PNNL-15041

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FINAL REPORT
July 2007

Prepared for the
U.S. Army Corps of Engineers
Under a Related Services Agreement
With the U.S. Department of Energy
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Pacific Northwest National Laboratory

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Portland District, Portland, Oregon
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Abstract

This document provides a synthesis of biological research on juvenile salmonid passage and survival at Bonneville Dam from 1939 to 2005. This review of available literature was prepared by the Pacific Northwest National Laboratory for the U.S. Army Corps of Engineers (USACE). It involved acquiring a copy of every pertinent report or journal article through 2005, writing an annotated bibliography, and then writing a report that summarizes and synthesizes available information in a decision-support document. Studies of interest and the arrangement of chapters after the Chapter 1-Introduction include Chapter 2-Forebay Distribution and Approach; Chapter 3-Passage, including sections on Major Metrics, Surface Flow Outlets, Fish-Guidance Efficiency, and Fine-Scale Distributions; Chapter 4-Survival, and Chapter 5-Optimizing Fish Passage Strategies at Bonneville Dam.

Summary

This document provides a synthesis of biological research on juvenile salmonid passage and survival at Bonneville Dam from 1939 to 2005. This review of available literature was prepared by the Pacific Northwest National Laboratory for the U.S. Army Corps of Engineers (USACE). It involved acquiring a copy of every pertinent report or journal article through 2005, writing an annotated bibliography, and then writing a report that summarizes and synthesizes available information in a decision-support document. Studies of interest include those on project-wide route-specific passage (and related efficiency and effectiveness metrics), fish survival (direct and indirect), fish-guidance efficiency (FGE) of powerhouses and units, predation in the forebay and tailrace, fish behavior on forebay approach and egress, and surface passage. The chapter on juvenile salmonid passage includes a review of available passage distribution data (horizontal, vertical, and diel) for juvenile salmon.

Forebay Distribution and Approach

Fish approach the Bonneville Project following bulk flow, and the distribution of fish passage among the Bonneville Dam First Powerhouse (B1), the spillway, and the Bonneville Dam Second Powerhouse (B2) is well correlated with the discharge distribution. Dam operations affect the distribution of fish passage among structures because fish movement from one forebay to another is minimal after the initial distribution by bulk flow. Vertical distributions of fish in forebay areas upstream of dam structures are highly skewed toward the water's surface, and therefore surface flow bypasses have potential to be efficient and effective. Horizontal distribution in forebays of the two powerhouses revealed areas of concentration. At B1 these areas were upstream of units 4-6 in spring and upstream of units 4-6 and toward the north end of the powerhouse in summer. At B2 fish concentrated primarily in the south end near or in a large eddy and in a smaller eddy on the north side of the forebay.

Average travel rates from release sites to the project were relatively quick. In kilometers per hour, rates averaged 2.1 for subyearling Chinook salmon, 2.3 for yearling Chinook salmon, and 2.6 for steelhead. These results indicate that radio-tagged fish are actively moving downstream and not holding for prolonged periods of time.

Average hourly residence times in forebays were short except for B1, when B2 was assigned the generation priority for the project after 2000 or for steelhead at either powerhouse (Table S.1). Short residence times at the spillway and B2 reduce the risk of predation.

Table S.1. Average Hours of Forebay Residence for Chinook Salmon and Steelhead

Species / Age Class	B1	Spillway	B2
Yearling Chinook salmon	2.2	0.2	0.5
Steelhead	5.4	0.3	3.0
Subyearling Chinook salmon	4.4	0.4	0.2

Juvenile Salmonid Passage

Major Passage Metrics

Maximizing fish passage by non-turbine routes (fish passage efficiency or FPE) may or may not be the best goal to maximize project survival depending upon the ranking of survival of all major routes at

Bonneville Dam. Prioritizing routes by survival rate would seem to be a logical first step toward the goal of maximizing project survival, and therefore a thorough understanding of route-specific survival is critical for choosing the best routes for fish. After routes are ranked from highest to lowest survival, the next step would be to adjust project operations to maximize passage through the safest routes. In the survival chapter, we made an effort at ranking routes, as follows:

- Survival was always highest through the B2 Corner Collector (B2) - all species.
- The B2 Juvenile Bypass System (B2 JBS) typically ranked second or tied for first - all species.
- Ranking among the other three routes, the B1 JBS, spillway, and B1 sluiceway, varied substantially, with no consistent pattern evident.

These rankings were determined by inspecting summary tables and figures appearing in the reports (Counihan et al. 2005, 2006). Depending on the species and prevailing condition, spillway survival was often low, ranking 4th or 5th of the five routes available. This may suggest that spill is not particularly beneficial for enhancing passage survival for the population at large. However, spilling water also enhances egress conditions in the tailrace and likely contributes to the high survival realized at the corner collector.

If turbines sometimes provide a safer route than some spill bays, then using spill to maximize FPE may not be consistent with the goal of maximizing project survival. However, if the safest routes turned out to be non-turbine routes, and the goal was to maximize passage by non-turbine routes, then the discussion and recommendations in the next two paragraphs make sense.

The most efficient approach to increase non-turbine passage is to optimize percent flow to the B1-sluiceway and the B2 Corner Collector (B2CC) because these routes can reduce turbine passage by out-competing adjacent turbines for fish. The spillway cannot compete directly with turbines for fish. Spill should not be eliminated, but it may be possible to reduce reliance on spill to pass juvenile salmonids by fully realizing all potential benefits of surface passage through structural and operational changes at the powerhouses. Turbines are about as efficient as the spillway at any percent of project flow (Ploskey et al. 2006b), but surface routes are much more efficient than turbines at low percent flow. The average percent of B1 flow through the B1 sluiceway (1%-2%) is well below an optimum amount of 10%, but hopefully planned improvements in that system will greatly increase its performance in the future. Given the very high effectiveness of surface routes at the lowest flows, we recommend testing the use of many low-flow surface outlets at B1 versus the use of a few outlets passing equivalent flow. Regressions indicated that increasing surface-flow percentages of B1 flow from 1% to 10% could increase B1 sluiceway-passage efficiency from 40% to 83%, and this clearly indicates that juvenile salmonids preferentially select surface outlets over adjacent turbines. Increasing B2 flow to the B2 sluiceway from 4% to 15% could increase fish passage from 31% to 62%. The high effectiveness of surface outlets and their proximity to turbines should make them the first choice of managers for optimizing flow to increase non-turbine passage, rather than spill. Without structural modification, attaining 10% B1 flow to the sluiceway requires shutting down turbines, which is how 50% to 100% of B1 flow to the sluiceway was possible at times.

Given the B2 powerhouse priority, it is difficult to imagine increasing the percent of B2 flow to the B2CC much above the median baseline of 4% observed in 2004 and 2005. Previous observations of 10% to 15% of B2 flow to the B2CC always occurred at night when turbines were shut down to accommodate increased spill at night. The installation and testing of a smolt guidance device in the B2 forebay may be a viable alternative to increasing percent flow from 4% to 15%. We also recommend testing ways to reduce shedding of turbulence from piers at units 11 and 12 as these turbulent cells tend to push lateral flow away from the face of the powerhouse. An economical approach would be to cover spare trash racks with a plywood veneer and install them into trash-rack slots on top of existing un-blocked trash racks to assess potential benefits to B2CC efficiency and effectiveness.

The percent of spill clearly has an overriding influence on spill and fish-passage efficiency and likely will always be an important tool to improve spill and fish-passage efficiency, but spill effectiveness is nearly constant at just over 1:1 over a wide range of percent spill. Spill has been and probably will continue to be used to increase non-turbine passage at Bonneville Dam, but it is not an efficient use of water because the project has two islands that isolate spillway flow from powerhouse flow before fish can select a preferred route. Consequently, spill efficiency will always be directly proportional to percent spill, with effectiveness ranging from about 0.7 to 1.3.

Surface Flow Outlets

PSC

Based on the collective data during the 1998-2000 Prototype Surface Collector (PSC) evaluation period (summarized by Johnson and Carlson 2001), researchers found that the surface bypass concept as applied at B1 was an efficient way to collect juvenile salmonids and minimize turbine passage. Fish collection efficiency estimates from hydroacoustics, radio telemetry, and acoustic telemetry methods comported reasonably well. The highest quality and most applicable data for fish collection efficiency are from the 2000 evaluation, because of the large sample sizes and because the PSC covered units 1-6 that year. The PSC only covered units 3 and 4 in 1998, and units 3 through 6 in 1999. For the purposes of planning and analysis for constant turbine operations, at one PSC slot opening, the following fish collection efficiency estimates should be used:

Yearling Chinook salmon	76%
Steelhead trout	82%
Subyearling Chinook salmon	84%

Fish collection efficiency for the PSC was similar between spring and summer, i.e., it did not decrease in summer but stayed largely unchanged while the run composition changed. This is not true of other smolt bypass approaches that have decreasing efficiency as the season progresses. Fish collection efficiency for the B1 PSC was higher than that for the surface bypass and collector SFO at Lower Granite Dam and comparable to that for the Wells Dam SFO. Extending the PSC to units 1 and 2 in 2000 was worthwhile because the surface bypass entrances at units 1 and 2 passed a substantial proportion of total PSC fish passage (23%-28%). According to radio telemetry data from 2000, the PSC would have increased fish passage efficiency at Bonneville Dam 18% for steelhead and 10% for Chinook salmon had it been a functional bypass system. The PSC was twice as effective (percentage fish divided by percentage water) as spill at passing fish at Bonneville Dam in 2000.

The B1 PSC showed promise as a powerhouse retrofit SFO, but it was not followed by a full production structure, a state it remains in to this day. The main reasons for this included

- uncertainty about fish response to forebay flow fields from a ramped entrance structure
- complexity of the conveyance and outfall structures
- uncertainty about fish injury rates at high flow outfalls

- commitment to the B2 Corner Collector and associated designation of B2 as the priority powerhouse at Bonneville Dam
- cost (~$200M).

The PSC evaluations demonstrated the efficacy of a powerhouse retrofit SFO for B1. Lessons learned from the PSC will be applicable to any future SFO development efforts at B1.

B1 Sluiceway

Based upon all available seasonal estimates from hydroacoustic and radio telemetry studies, the efficiency of the B1 sluiceway relative to B1 was correlated with the percent of B1 flow to that route. Within-season day and night estimates show the full range of effect much more clearly. B1 sluiceway efficiency increased very rapidly at low levels of percent flow. On average, the percent of B1 passage through the B1 sluiceway was about 40% at 1% of B1 flow (the minimum flow), 73% at 5% flow, 83% at 10% flow, and 88% at 15% flow.

Future SFO development at B1 is underway with the planned removal of the wall between the current sluiceway and the old juvenile bypass channel in 2007. This will increase channel capacity and allow all outlets above Unit 1 to be left fully open without limiting channel capacity for several gates further upstream. There also are plans to install floating gates to follow forebay elevation and produce a constant discharge. There are also possibilities for a new powerhouse retrofit SFO. Options would entail new conveyance and outfall structures, perhaps for a partial or full powerhouse Alternative A, a B1 corner collector with or without an associated behavioral guidance structure. Preliminary engineering is available for most of these options. We strongly recommend evaluating changes to the sluiceway system including its efficiency and effectiveness and fish survival after improvements are made. The survival study should include reference releases of fish from the existing outfall and potential alternative outfalls.

B2CC

Collection efficiency and effectiveness of the B2CC relative to B2 was highest for steelhead trout (66%-74%) and reasonably similar for the run-at-large (31%-32% in spring and 40%-44% in summer, as estimated by hydroacoustic sampling) to the estimate for Chinook salmon by radio telemetry (30%-37% in spring and 37%-40% in summer). For spring 2004 and 2005, fish-collection effectiveness relative to B2 averaged 7.3 for the run-at-large in spring, 6.5 for yearling Chinook salmon, and 13.7 for steelhead. In summer of those years, B2CC effectiveness relative to B2 was 7.3 according to the hydroacoustic estimate and 6.5 for subyearling Chinook salmon, according to the radio telemetry estimate.

There were too few seasonal estimates of B2CC efficiency for regression on percent of B2 flow to the B2CC, but daily hydroacoustic data from 2004 and 2005 show a trend similar to that observed for the B1 sluiceway. The percent of B2 passage through the B2CC was 30% at 4% of B2 flow (the minimum flow), 36% at 5% flow, 52% at 10% flow, and 62% at 15% flow. The remaining percentages of B1 or B2 passage at any percent flow represent what would pass through adjacent turbines.

The B2 Corner Collector is a permanent, long-term surface flow outlet at the B2 powerhouse. It has a state-of-the-art conveyance channel and outfall that passes juvenile salmonids with utmost safety into environs downstream of the dam. The B2CC takes advantage of the location of the old sluice chute relative to the forebay eddy to pass surface-oriented emigrants. The intention is for the B2CC not to be a stand-alone route, but rather to complement the intake screen system to protect fish at B2.

The reason for the higher collection efficiency and effectiveness for steelhead than for Chinook salmon is unknown, but efforts should be made to improve the collection of the latter species. As recommended above, we support testing of lateral flow modifications along the south face of the B2 powerhouse and a behavioral guidance device, given that it would be difficult to increase percent flow to the B2CC much above the median baseline of 4% without shutting down turbines. The installation and testing of a smolt guidance device in the B2 forebay was scheduled for 2007 but postponed.

Fish Guidance Efficiency

Fishery managers and analysts require estimates of FGE for certain evaluations, such as those involving fish passage models. FGE estimates are just one of many input parameters that are used to populate a passage model. Selecting a representative value for the species of interest can be challenging as witnessed by the variability in measured values and ever-changing screen systems. The difficulty is magnified if retrospective analyses are pursued, which requires establishing what effective FGE was at some point in history. Often such details are ignored or cannot be reasonably determined. In most cases a generic value that is considered representative is applied across dam configuration eras. This can result in rather coarse assessments.

The most recent generic FGE values for B1 and B2 were reported by Ferguson et al. (2005) as shown in Table S.2.

Table S.2. FGE Values for B.1 and B.2

	PATH		**NOAA – 1999 Configuration**	
Species	B1	B2	B1	B2
Yearling Chinook	41	43	38	44
Subyearling Chinook	---	---	16	18
Steelhead	---	---	41	48

These values were distilled from the complex of fyke net-based FGE estimates in the historical database. Staff used their judgment in selecting values that they believed were most representative of the general dam configuration pre-Biological Opinion (BiOp). Some of those estimates were then adjusted based on side-by-side PIT tag and fyke net data obtained at Snake River dams.

In viewing the collective FGE information obtained with fyke nets, hydroacoustics, and radio-telemetry, we submit the following synthesis and conclusions.

Establishing reliable, representative estimates of powerhouse FGE for use in retrospective passage modeling analyses for either B1 or B2 will be difficult. We could not readily identify any preferred set of estimates. Results vary by turbine unit, configuration, operations, and monitoring tool. There is no correct or best estimate of FGE available for application across all years. Furthermore, across and within years, so many conditions have been explored and tested that no typical or standard FGE can easily be distilled from the information. Managers seeking such estimates will have to make value judgments regarding the suitability of year-specific estimates for use in retrospective model analyses. Action Agencies, National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA Fisheries), and state and tribal biologists are currently engaged in such an effort as part of the 2006 remand process for the BiOp. Managers must determine what the further monitoring objectives are for Bonneville Dam and select the appropriate tool and method to satisfy them.

The fyke net method for estimating FGE seems best suited for evaluating different screen configurations in side-by-side comparisons. Since such evaluations involve only monitoring one or two units, this technique is not well suited for generating FGE estimates that represent performance across the entire powerhouse.

Hydroacoustic monitoring seems well suited for providing season-wide estimates of FGE if temporal and spatial coverage of the powerhouse is adequate. It is also the only practical method for documenting temporal changes in FGE over the migration period. An obvious shortcoming is the lack of species–specific information, but depending on management objectives, this may not be a handicap.

The radio-telemetry method provides sound estimates of the effective FGE across the entire powerhouse during the period tagged fish are passing the project. This may be the most representative estimate of FGE that could be adopted and applied in model analyses. Even so, only a few estimates from recent years are available. Estimates are best for units where the most fish are passing but numbers may be insufficient for units with the least passage.

Horizontal Distributions

The proportion of fish passage through B1, the spillway, and B2 was nearly proportional to discharge at each location. This observation was consistent throughout five years of full-project-passage assessment based upon both radio telemetry and hydroacoustic techniques.

Distributions of fish associated with passage through various routes within B1, the spillway, and B2 depend on discharge in that fish cannot pass through routes that are closed. This is why patterns of fish passage through B1 turbines varied a lot after the powerhouse priority was shifted to B2 in 2001 and thereafter. Different units were running in different years depending upon unit priority and outages for retrofitting or maintenance. The general correspondence between fish passage and discharge can be seen in route-specific plots of fish and flow passage for 2004 and 2005.

Horizontal distributions should always be plotted with route-specific discharge and interpreted in that context, something that was not always done in reports before 2004. The addition of discharge to distribution plots allows readers to get a sense of whether or not distributions were driven by project operations. Without plotting or considering the route-specific distribution of discharge, one might conclude that the fish passage distributions across B1 from 1996 to 2002 were simply not uniform or consistent.

However, the general relation between discharge and fish passage breaks down for surface flow outlets, because juvenile salmonids preferentially select these routes over other routes, and this selection leads to high measures of effectiveness (high efficiency with low water proportions). This is quite evident in lots of the density of fish passage by route. Surface passage routes have much higher efficiency at low flow proportions than do either the spillway or turbines.

Like the sluiceway at B1, the B2CC is a highly effective route of passage, clearly passing many more fish than any turbine unit and exponentially more on the basis of fish-per-unit of discharge. Lateral passage into the B2CC is not uniform. A majority of fish pass in the middle relative to the north and south sides, at least near the water's surface, where most fish are distributed. Intake piers from units 11 through 13 shed vortices and create turbulence that has an unknown effect on B2CC performance. Spare trash racks with plywood blocks on the upstream surfaces could be dropped into trash-rack slots in units 11 and 12 on top of existing trash racks to reduce shedding of turbulent flow. The blocked racks would act as cheap fillers for the space between the piers and could be put in and removed to create treatments that could be evaluated. The turbulence shed from the piers tends to push flow away from the powerhouse face and this could increase passage of fish into the north eddy instead of into the B2CC.

Non-uniformity of passage across openings to surface-flow outlets also was typical. Distributions of fish passing over chain gates at B1 sluiceway outlets sometimes favored the middle and sometimes the edges near piers according to video camera counts and later according to hydroacoustic counts after hydroacoustic sampling became reliable (after 2001). Acoustic camera (DIDSON) images of fish entering these outlets reveal a dynamic, seemingly unpredictable process mediated by time of day, vortices to the turbine below the opening, and other hydraulic characteristics, as well as the original direction of approach by fish (Ploskey et al. 2006c). The same was true for the lateral distribution of fish entering the PSC and the B2CC, where lateral distribution sometimes varied with depth.

The distribution of fish passage among bays with different spill deflector types may be more important than north or south skews in spillway passage distributions, both of which have been reported. Survival data suggest that fish passing through bays with older 14-ft-elevation deflectors may have lower survival than fish passing through bays with the new 7-ft-elevation deflectors (Counihan et al. 2003, 2006a). If passage among bays were uniform, we would expect 67% of fish to pass through bays with the older, apparently less fish-friendly deflectors. However, 2004 and 2005 operations apparently reduced the percentage passing through Bays 4-15 by 6%-9% over what would be expected. Hydroacoustic data indicated that 57%-60% of fish passage was through bays 4-15 instead of 67%. Since discharge patterns appear to be partially responsible for trends in spillway passage distributions, some tweaking of discharge to reduce the percent passing through bays with old spill deflectors may be warranted.

Numbers of radio tagged fish detected at the spillway each season between 1996 and 1999 were only sufficient to provide a broad description of passage trends by north and south halves of the structure, and estimates in later studies were reported only as a proportion of total project passage. At best, skews in spillway passage distributions could be described as weak in most years, with just over 50% to 65% of fish favoring one half of the spillway or the other.

Almost all hydroacoustic and radio telemetry studies reflect a strong skew toward the south end of the powerhouse. With very few exceptions across season, year, or methodology, units 11-14 (especially units 11 and 12) passed the majority of fish as compared to units 15-18 on the north half of B2. As with lateral fish passage across intakes at B1, distributions across turbine intakes at B2 were not uniform. Leaving turbine intake extensions (TIEs) out from units 11 through 14 undoubtedly facilitates a strong southerly flow of water along the powerhouse face toward the B2CC, and this is highly desirable for increasing fish passage at the B2CC. The TIEs retained on every other intake from Intake 15A through 18B help break up the flow toward the north eddy and likely increase passage and FGE at intakes between TIEs.

Turbine-intake extensions have created some predictable patterns in passage among intakes at B2, although horizontal distributions across intakes of the same turbine typically were not uniform nor predictable based on hydroacoustic sampling at B1. Discharge through Bonneville Dam turbines typically is highest at the south (A) intakes, intermediate at the middle (B) intake, and lowest at the north (C) intakes, but passage seldom follows the discharge pattern. Hydroacoustic data have sometimes shown about 10% higher passage through intakes between TIES than intakes behind TIEs at B2 (e.g., Ploskey et al. 2002c; Ploskey et al. 2003). Monk et al. (1999b) noted that FGE for yearling Chinook increased 20% for intakes between TIEs.

Vertical Distributions

A number of investigators have assessed vertical distribution of fish upstream of passage structures, but those data do not accurately reflect distributions of fish committed to passage. About 100 ft upstream of trash racks at B2, fish were distributed very high in the water column, and those distributions seemed inconsistent with low in-turbine estimates of FGE (Ploskey et al. 2002a) but were fairly consistent with vertical distribution estimates for the B2CC (Ploskey et al. 2005, 2006c). Fish upstream of the PSC and immediately upstream of B2 trash racks were less highly skewed toward the water's surface (Ploskey et al. 2002a and 2002c).

The vertical distribution at surface flow outlets first depends upon the depth of the outlet. The B1 sluiceway is very shallow and yet highly efficient, consistently passing over 33% of B1 fish passage. When the 40- to 45-ft-deep PSC took fish at all depths although slightly more entered in the upper half than in the lower half, and the PSC also was highly efficient and effective. Given that vertical distributions of fish in B1 turbines are not skewed toward the top of the intake and fish occur at many depths, the depth of the PSC was not wasted. At the PSC, entrance depths varied by species and time of day according to radio telemetry sampling. The vertical distribution of passage at the B2CC was highly skewed toward the surface of the water, even though about 24 ft of depth is available for passage.

At the spillway, the vertical distribution of passage peaks within a few feet above the elevation of the ogee crest, and this could be undesirable in terms of survival. Fish passing deep and close to the ogee sometimes experience higher incidence of injury and mortality than fish passing from higher in the water column (Thomas Carlson, Personal Communication).

In-turbine distributions at both B1 and B2 are not highly skewed toward higher elevations as they often are at upstream hydropower projects. There also is evidence of a skew toward both higher and lower elevations at B1 intakes, especially in summer (e.g., Ploskey et al. 2002c). In-turbine vertical distribution data are generally consistent with FGE estimates for each powerhouse where FGE is often 50% or less.

Diel Distributions

It is easiest to talk about diel distribution by type of passage route (turbines, spillway, and surface passage outlets) because trends are more apparent and consistent than they are by structure (B1, B2, and the spillway). However, it is very important to differentiate between diel patterns that are driven by diel shifts in project operations and discharge and natural patterns that occur when operations are relatively constant.

The diel patterns of passage through turbines and the spillway suggest that some fish may be holding in forebay areas during the day and passing at night, although short radio telemetry residence times suggest that holding cannot be prolonged (a few hours at most). Nevertheless, the crepuscular peaks in passage in bypass systems, fyke net samples, and hydroacoustic samples would only result if some delay occurred. The loss of visual position cues may be responsible for increased fish passage into turbines just after sunset because smolt passage at turbine units is not a function of increased flow at that time.

Turbines

When turbines run 24 hours per day, fish passage usually is crepuscular with peaks occurring after sunset and about dawn, and passage usually is higher at night than it is during the daytime. These trends are not unlike what can be observed for juvenile bypass structure (JBS) data except that there is a delay of several hours in the observed peaks for JBS data since fish may delay in gatewell slots. When turbines dominate project operations, as they did in 2001, similar diel patterns can be observed for total project passage, but in general a single turbine running the same discharge 24-hours per day provides the best look at a typical diel pattern.

Atypical diel patterns of passage at turbines result from turbines not running consistently over a diel cycle, so it is important to show discharge on diel plots, if turbine operations are unknown. Turbine discharge and fish passage at B1 in spring and summer 2005 provide a good example of an atypical diel pattern driven by turbine operations. These diel patterns are of interest because they show the degree to which diel patterns can be altered by operations. Another atypical example of a diel trend for turbine passage was observed in B2 turbine passage in summer 2005, when most turbines between unit 11 and 18 were shut down to provide water for increased spill at night.

Spillway

In a couple of cases when discharge was held constant throughout 24-hour periods (e.g., during the drought of 2001 and for six days in summer 2004), hourly passage estimates clearly indicate that nighttime-dominated diel patterns are not entirely due to increased discharge at night. In the drought year of 2001, when spill was nearly constant 24 hours per day, Ploskey et al. (2002c) described diel trends with a decline during daylight hours, an increase at 2100 hours in spring and 2200 hours in summer. Except for those periods of constant discharge for 24 hours, separating a natural diel pattern of passage at the Bonneville Dam spillway has been difficult because discharge usually is much higher at night and spill efficiency is directly correlated with discharge. With the exception of yearling Chinook salmon in 2000, all other studies of radio-tagged fish showed higher hourly rates of spillway passage at night than during the day.

Surface Flow Outlets

Most research indicates that a majority of fish pass surface-flow outlets during daylight hours, unlike passage through turbines and the spillway described above. Netting data by Willis and Uremovich (1981), hydroacoustic data collected after 2001, and Dual Frequency Identification Sonar (DIDSON) video clips all indicate that B1 sluiceway passage is higher at night than it was during the day. Results at the 20-ft-wide slot at the PSC showed higher passage at night than during the day based upon hydroacoustic sampling (Ploskey et al. 2001b, 2002a and b) and radio telemetry sampling (Evans et al. 2001a; Evans et al. 2001b). The B2 sluiceway outlet (B2 sluice chute before 2004 and B2CC thereafter) had a daytime-dominated diel pattern of fish passage (Magne et al. 1986; BioSonics 1998; Ploskey et al. 2001a; Ploskey et al. 2005, 2006c).

The predominance of fish passage through surface routes during the day indicates that smolts are readily entering those outlets, but DIDSON video indicates that smolts often are holding upstream of outlets at night. Day and night DIDSON recordings of smolt behavior upstream of the B1 sluiceway in 2005 (Ploskey et al. 2006c) certainly support the nighttime holding hypothesis for that location. Not only were smolts holding in large loose schools at night, they were subjected to intensive predation, whereas during the daytime tight schools of smolts readily entered B1 Sluiceway Outlet 3C, and predation events were relatively rare. Similar recordings showing increased holding and predation at night in the south eddy upstream of the B2CC were recorded in 2004.

Survival

The safest passage routes at Bonneville Dam are the B2CC and the B2 JBS. Operations that maximize passage through these routes are advantageous to juvenile salmonid populations tested so far. The ranking of survival among the three other routes reveals no clear and consistent pattern. Survival at the B1 sluiceway should be re-evaluated after improvements are made in 2007 and 2008 and reference releases downstream should include the existing outfall and another potential outfall site. In our opinion, the affects of deflector elevation on spillway survival are becoming clearer. Based on radio tag data, the lower deflector yielded higher (or equivalent) survival than the 14-ft deflector, regardless of the spill level, species, or season. The only exception may be for steelhead under gas cap spill levels. It appears that the lowered deflector is the preferred configuration, although another year of testing may be prudent. Survival through minimum gap runner (MGR) turbines tested at Bonneville appears equivalent to that realized for smolts passing through standard units. Thus, the MGR provides no discernable improvement in turbine passage survival. Balloon tag survival estimates are clear on this point, although the potential for some delayed effects associated with injury could be manifested well downstream from the dam. Radio tag-based survival estimates did not shed light on this potential effect. Telemetry estimates of survival through a standard unit were not available for direct comparison with the MGR estimate.

Comparisons of survival estimates from assorted investigations can be confusing at times. Nearly every treatment estimate reported is probably best viewed as a relative estimate of survival. The control release sites establish the reference point, and the recovery of control fish constitutes the tag recovery proportions for the condition specific to that time and space.

Not all studies have released controls in the same locations. Even within a multi-year study conducted by the same investigation team, the location of control release sites can vary. Similarly, the location where, and the means by which, treatment groups are released has varied across studies. These attributes can, in turn, affect the survival estimates. Managers must select those estimates that best reflect the zone of interest and the set of conditions that are of primary concern and then focus on survival estimates that best bracket those parameters. We have attempted to provide that information in this report to guide those management decisions.

The absolute values of a number of survival estimates that were obtained using radio telemetry are suspicious, since they approach or exceed 100%. Indications are that they were likely biased high. This was because, in several instances, a key assumption was violated. Independent tests revealed that some known dead fish bearing active tags released in the tailrace were subsequently detected at downstream detection transects. This raises the possibility that some smolts killed during dam passage could have drifted to the detection sites and been logged as live fish. The extent to which this actually occurred cannot be accurately determined. Perhaps relocating the downstream detection sites could avert this problem in the future.

Despite the uncertainty regarding bias associated with the absolute values of some telemetry estimates, the technique can still be used to generate acceptable estimates of relative survival. Thus, use of this tool for determining optimal passage routes or operations appears sound if based on relative estimates. Conversely, it may require caution on the part of managers to rely on these telemetry-based survival estimates as input for passage modeling at Bonneville, because they may be mischaracterizing the true magnitude of passage effects.

Radio tags provide a sound means to evaluate the effects of recent operations, using dam survival estimates derived from route-specific estimates. Furthermore we see this as an instructive performance index. A consistent pattern was evident in both 2004 and 2005. During the gas cap-night condition, survival was highest for all species. The only qualification being that, in 2004, survival of subyearling Chinook was uniform across the spill conditions. If future conditions need to be evaluated, a fruitful analytical approach is at hand. Again, we suggest the readers consider these relative survival estimates, not absolute survival probabilities.

Other mark-recapture approaches may not experience the difficulties unique to telemetry, but they are not without limitations. The absolute values of survival estimates obtained using freeze brands varied widely depending on the location at which the controls were released. As a consequence, those investigators expressed results as relative differences in recovery proportions to avoid the complication (Dawley et al. 1993b).

Absolute values generated using balloon tags appear sound and are readily interpretable. But of course they only reflect direct effects. Managers intent on analyzing the full passage effects through the Federal Columbia River Power System (FCRPS) desire estimates that reflect total passage effects. For such purposes, managers will be forced to select judiciously from the estimates reported to date and select those that best reflect the zones and class of effects they wish to incorporate in their analyses. We cannot identify a best universal set of estimates that are suitable for all applications.

Preface

This report was prepared by the Pacific Northwest National Laboratory (PNNL), Richland, Washington; BioAnalysts, Inc.; and BAE Systems, Inc. The U.S. Army Corps of Engineers, Portland District (USACE - Portland) provided funding, and Blaine Ebberts and Dennis Schwartz provided oversight.

Acknowledgments

Randy Lee and Dennis Schwartz (USACE - Portland) provided historical information from their report, *Fish Guidance Efficiency Improvements 1995-2002 Prototype Design and Evaluations*. Scott Evans, Rachael Reagan, and Tim Counihan (U.S. Geological Survey [USGS], Columbia River Research Laboratory, Cook, Washington) graciously provided radio telemetry reports on fish passage and survival. Rudd Turner graciously provided portable document files (PDFs) of the USACE Reservoir Control Center's Annual Fish Passage Plans for 1984-2005) and the annual reports of the Columbia River Water Management Group's Committee on Fishery Operations for 1978-1983, which preceded the annual fish passage plans. These plans provided valuable information about changes in dam structure and operations since 1978. The USACE Portland District Library loaned many of the reports that were scanned into PDFs for the digital video disk (DVD) accompanying this report. Eric Fischer (Pacific States Marine Fisheries Commission or PSMFC), added a few abstracts to the annotated bibliography, standardized the abstracts, and requested permission to reproduce copyrighted materials. Jina Kim, also with PSMFC, checked figure numbering and assembled the list of figures and tables. Mary Ann Simmons helped with editing, and Theresa Gilbride was the editor.

Acronyms and Abbreviations

AFEP	USACE Anadromous Fish Evaluation Program
AT	Acoustic Telemetry
B1	Bonneville Dam First Powerhouse
B2	Bonneville Dam Second Powerhouse
B2CC	B2 Corner Collector
BiOp	Biological Opinion reports published by NOAA Fisheries
BPA	Bonneville Power Administration
CBE	combined bypass efficiency
CENWP	U.S. Army Corps of Engineers – Portland District
CFD	computational fluid dynamics
cfs	Cubic feet per second
CWT	coded wire tags
DE	discovery efficiency
DIDSON	Dual Frequency Identification Sonar
DSM	demand side management
DVD	digital video disk
ESBS	extended length submerged bar screens
FCRPS	Federal Columbia River Power System
FGE	fish guidance efficiency
FPE	fish-passage efficiency
H	hour
HA	Hydroacoustic
HRB	Hood River Bridge
ID	identification
ITC	B2 ice/trash sluice chute
JBS	juvenile bypass system
JDA	John Day Dam
kcfs	thousands of cubic feet per second
km	kilometer
MGR	minimum gap runner
NOAA Fisheries	NOAA National Marine Fisheries Service (formerly called NMFS)
NOAA	National Oceanic and Atmospheric Administration
PATH	Plan to analyze and test hypotheses

PCC	Prototype Corner Collector at B2 sluiceway
PDF	Adobe Portable Document Files
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
PSC	Prototype Surface Collector
PSMFC	Pacific States Marine Fisheries Commission
RCK	Rock Creek
RT	radio telemetry
SFO	surface flow outlet
STS	submerged traveling screens
TDA	The Dalles Dam
TDG	total dissolved gas
TIEs	turbine intake extensions
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
VBS	vertical barrier screen

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1.0 Introduction

This document provides a synthesis of biological reports on downstream fish passage and survival at Bonneville Dam from 1939 to 2005. The document was prepared for the U.S. Army Corps of Engineers (USACE) – Portland District under the Anadromous Fish Evaluation Program (AFEP) by the Pacific Northwest National Laboratory (PNNL), Richland, Washington, BioAnalysts, Inc., and BAE Systems, Inc.

1.1 Scope and Objectives

The review of available literature for juvenile salmonid passage at Bonneville Dam involved acquiring a copy of every pertinent report or journal article written between 1939 and 2005, writing an annotated bibliography, and then writing a report that summarizes and synthesizes available information in a decision-support document. Studies of interest were on project-wide route-specific passage (and related efficiency and effectiveness metrics), fish survival (direct and indirect), fish-guidance efficiency (FGE) of powerhouses and units, predation in the forebay and tailrace, fish behavior on forebay approach and egress, and surface passage. The fish passage part includes a review of available distribution data (horizontal, diel, and vertical) for juvenile salmon. This report does not repeat the results of previous review and synthesis studies but cites them, includes Adobe portable document files (PDF) of the reviews, and then summarizes subsequent reports. Where no previous review exists for a subject area, all reports were reviewed and synthesized. This review does not cover hydraulic studies. This report consists of three parts:

1. this document, which summarizes and synthesizes research on juvenile salmonid passage at Bonneville Dam from 1939 through 2005
2. an annotated bibliography summarizing each report we reviewed
3. a digital video disk (DVD) containing PDFs of more than 170 papers and reports reviewed and an HTML index with hyperlinks to these documents. The index is sorted by authors and date.

1.2 Background

Bonneville Lock and Dam consists of several dam structures that together complete a span of the Columbia River between Oregon and Washington at River Mile 146.1, about 40 miles east of Portland, Oregon. From the Oregon shore north toward Washington, the current project is composed of a navigation lock, a 10-turbine-unit First Powerhouse (B1), Bradford Island, an 18-gate spillway, Cascades Island, and an 8-turbine-unit Second Powerhouse (B2; see Figure 1.1).

Bonneville Dam was formally authorized by Congress in the Rivers and Harbor Act of 30 August 1935. This act also provided the authority for the construction of additional hydroelectric generation facilities when requested by the Administrator of the Bonneville Power Administration (BPA). The spillway and B1 were constructed between 1933 and 1937 without specific regard for protecting juvenile salmonids migrating downstream. Public Law 329 by the 75th Congress, August 20, 1937, provided authority for the completion, maintenance, and operations of Bonneville Dam. Administrative letters of

BPA in January and February 1965 stated the need for the construction of B2. Construction of turbine units 11 through 18 and two fishway units began in 1974 and was completed in 1982.

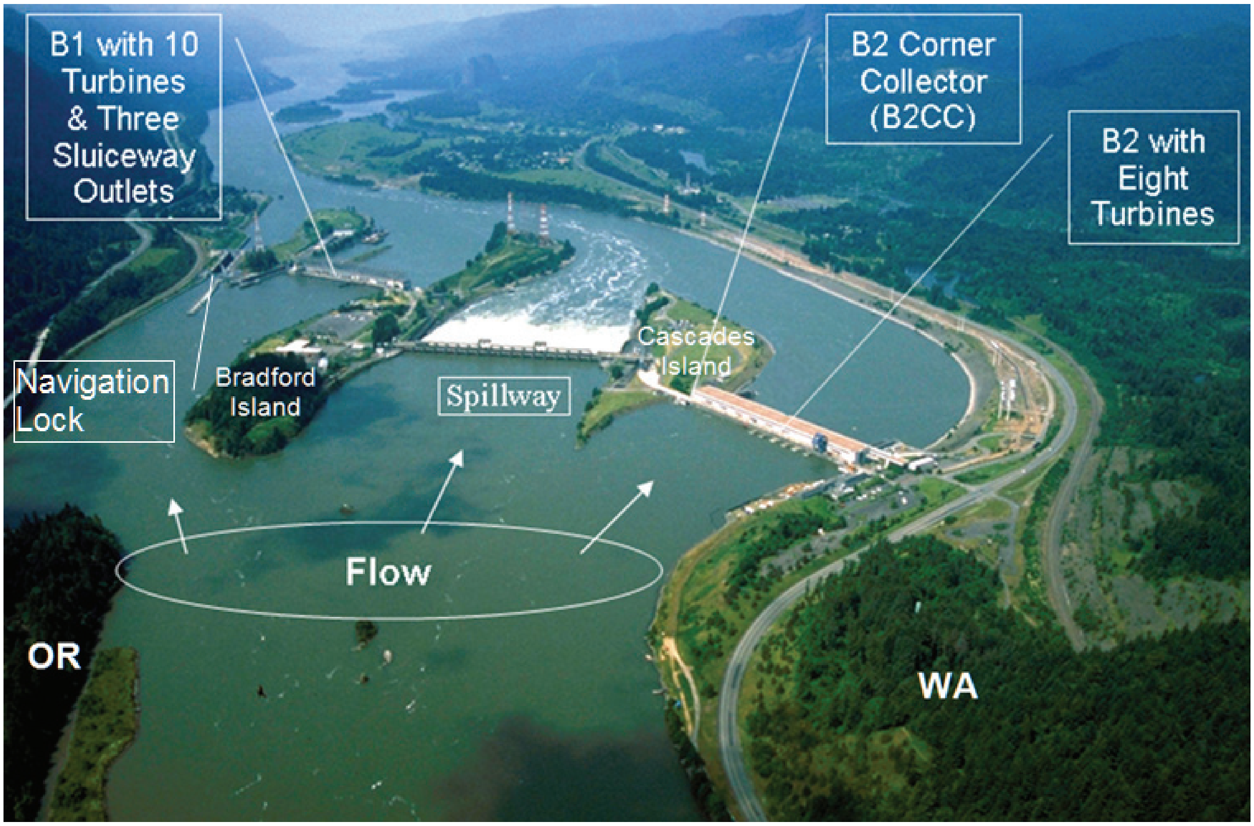

Figure 1.1. Plan View of the Bonneville Dam Project. The B1 sluiceway outlets and the B2 Corner Collector (B2CC) are surface overflow passage routes.

Principal fish passage routes include the spillway and two powerhouses, but within each powerhouse, passage can be through ice-trash sluiceways, turbines, or the juvenile bypass system (JBS). Smolts enter the JBS after encountering screens in the upper part of the turbine intakes. Screens divert fish to gatewell slots where they pass through orifices opening into a bypass channel which carries them to an outfall downstream of the dam. The JBS system at B1 was removed in 2004 because other routes are safer for fish. In 2003, the ice-trash sluiceway channel at B2 was modified and lengthened so that water was discharged downstream from the tip of Cascades Island. The modified sluiceway is hereafter referred to as the B2 Corner Collector (B2CC). All modifications were specifically designed to maximize non-turbine passage and survival of juvenile salmonids.

The following background information is intended to provide a brief history of changes to juvenile fish passage routes at Bonneville Dam and a general chronology of smolt-passage research. The intent is to provide an overview of structural and operational changes that have been evaluated.

There has been a long history of juvenile salmonid research at Bonneville Dam (see Tables 1.1 and 1.2, which are presented at the end of this chapter due to length). Initial survival studies on juvenile salmonids were conducted by the U.S. Fish and Wildlife Service from 1938 through 1944 using gossamer bags and balloons; these studies estimated turbine passage survival for juvenile fall Chinook salmon to be from 85% to 89%. In 1953, 1954, and 1956 additional direct survival studies, generally referred to as "balloon experiments" because auto-inflating balloons were used to retrieve fish introduced into turbines, below spill gates, or downstream of the dam, were conducted by the USACE's Resident Biologist and the U.S. Fish and Wildlife Service. There also was considerable work on the diel distribution of smolt passage in the late 1940s and early 1950s. In 1970 and 1971 two studies were conducted regarding hydraulic effects on egress and forebay pool and tailwater effects, respectively. In 1969, 1971, 1980, and 1981 the sluiceway at B1 was studied by the Fish Commission of Oregon with funding from the USACE Portland District.

Research on juvenile fish passage was relatively sparse during the 36-year period from 1939 through 1974, but it increased substantially in the 1980s, especially after the Bonneville Second Powerhouse was completed in 1982, and it remained high through 2005 (Table 1.1). Starting in 1981, submerged traveling screens (STS) that were designed in the 1960s and 1970s were tested at B1 to determine fish guidance efficiency (FGE) at various screen angles (Krcma et al. 1982). The relatively high FGE estimates ended most fish-guidance research at B1 until the new navigation lock was completed in 1988. Guidance levels from May 30 to June 5, 1988 were considerably less than in 1981 (Gessel et al. 1989); these results and other low estimates for turbines at Powerhouse 2 sparked a lot of research. The B1 STS have been studied by netting in the late 1980s and 1990s and since the late 1990s by hydroacoustics and radio telemetry methods.

A prototype extended length submerged bar screen (ESBS) was installed in 1999 and specifically tested in 2000 and 2001. It was still present during the 2002 studies but was removed in 2003 because both netting and hydroacoustic sampling revealed a significant decline in FGE in summer that made the screen no more effective than existing STS. In 2004, the STS at B1 were not deployed for the first time in many years because studies indicated that survival was better for fish passing through turbines than for fish screened at B1 and passed through the existing juvenile bypass system. Other survival data has raised questions about whether bypass systems increase smolt survival (Dawley et al. 1993a and b). New minimum gap runners were installed in Unit 6 and survival was evaluated in 2000; remaining B1 turbines should all have these new runners by 2008 (Portland District 2002).

In winter 1997, the Portland District installed a Prototype Surface Collector (PSC) with deep variable width slots at units 3 through 6 of B1, and the efficiency and effectiveness of 5- and 20-ft slots at Units 5 and 6 were extensively studied by fixed-aspect hydroacoustics, multi-beam acoustics, and radio telemetry in 1998 (see Johnson and Giorgi 1999 for a review). PSC entrances were 40- to 46-ft deep depending upon forebay level, and the mean velocity at the entrance ranged from 3.8 to 8.3 fps, depending on slot width, resulting in flows of 1,700 cfs for 5-ft slots and 3,300 cfs for 20-ft slots. Unit 5 was studied again in 1999, and the PSC was extended to units 1 through 6 and tested with the above mentioned methods and with acoustic telemetry in 2000 (see Johnson and Carlson 2001 for a synthesis of results).

Over the years, the Portland District has developed spill patterns and rates to facilitate egress of smolts from the spillway tailrace, but structural changes to benefit fish were limited to installation of spill deflectors in 13 of 18 bays in 1975 and of six new deep deflectors at bays 1-3 and 16-18 in 2001. Spill deflectors reduce gas supersaturation by directing flow along the surface of the tailrace rather than allowing it to plunge. The new deflectors added in 2001 were submerged 7 ft deeper than the existing ones, and generated considerably lower total dissolved gas (TDG) pressures than the old deflectors for low tailwater conditions ranging from 10.2 to 13.7 ft. For example, the difference in the mean TDG saturation (old deflector minus new deflector) for a specific discharge of 7,000 cfs per bay was 6.1% (Schneider et al. 2003). The two types of spillway deflectors have been studied in direct survival studies using balloon tags (Normandeau et al. 1996 and 2003) and indirect survival studies using radio telemetry (Counihan et al. 2006a and 2006b). In both cases, trends were apparent, although usually not significant. There are a number of factors governing spill at Bonneville, including TDG limitations and effects of spill on adult passage. The former may preclude the ability to spill 100,000 cfs all of the time in spring.

After completion of B2 in 1982, it took researchers about a decade of hard work to maximize FGE by adjusting the deployment depths of the STS and recommending structural modifications (Gessel et al. 1991). The Portland District had added three streamlined trash racks in the upper part of the turbine intake and turbine intake extensions (TIEs) to every other intake across the powerhouse by 1993. Nevertheless, guidance rates were still less than desirable in spring and poor in summer. The TIEs are still removed by early July because they do not facilitate subyearling guidance in summer as well as they guide yearling salmonids in spring. Performance of various measures tested from 1983 to 1994 (Gessel et al. 1991) were highly variable among years, seasons, species, intake slot, and unit and powerhouse operation. The number of fish entering and being guided by the non-TIE intake slots was higher under four and six than eight-unit operation; this suggested that powerhouse load (number of units on) has an effect on the strength of the lateral flows directed toward each corner of the powerhouse, and that TIEs produce a varying effect on intake distribution that decreases from four to six units of operation, and disappears with eight units (Portland District 2002).

Based upon a review of FGE results, researchers with the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration (NOAA Fisheries) concluded 1) the flow field above the STS and into the gatewell slot is restricted and needs to be increased, and 2) the bulk flow moving laterally across both the north and south ends of the powerhouse in the near forebay needs to be redirected into the intake because the forebay hydraulic environment greatly complicates the sensory cues presented to the fish. Researchers recommended that subsequent hydraulic evaluations need to be examined to look at the complex interactions between bulk forebay flow and the flat face and intake structures for clues on how to improve FGE.

In response to these findings, the USACE Portland District started research in 1998 to collaborate and support the construction of two new fish passage improvement projects at B2 (as described in Portland District 2002). The first of the two improvements included modifications to the current gatewell intake structure to direct more flow up into the gatewell slot. These modifications included new vertical barrier screens (VBS), a gap closure device, and a turning vain. With these improvements, the hydraulic capacity of the gatewell slot went from 270 cfs to 480 cfs, and the STS top gap flows were reduced from 215 cfs to 90 cfs. Research was conducted in 2001 to measure the FGE improvements in modified Unit 15, and netting and hydroacoustic results were very encouraging. The netting estimates were the highest FGE values measured at B2 since testing began in the early 1980s (Monk et al. 2002). Summer FGE for subyearling Chinook salmon averaged 57%. Hydroacoustic FGE estimates for all run-of-river salmonids combined was 72% for spring and 50% for summer. In 2002, the USACE modified Unit 17 to be similar to modified Unit 15. Netting and hydroacoustic results again were encouraging in 2002 (Monk et al. 2004; Ploskey et al. 2003, respectively) although there was greater variation among intakes of Unit 17 than there was among intakes of Unit 15 and FGE was lower at Unit 17 than at Unit 15.

The ice and trash sluice chute at B2 was recognized as an exceptionally effective way to pass juvenile fish by Fishery Field Unit researchers in the 1980s, but fish managers limited its use in the 1990s and from 2000 through 2003 because of egress problems and predation in the tailrace downstream of the original ice and trash sluice chute outfall. Exceptions included sluice-chute tests in 1998 and the B2CC evaluation in 2004. In both of these years, TIEs were removed from units 11 through 14 in spring and summer to facilitate flow toward the south corner of B2. Since the sluice chute channel was modified in late 2003 and early 2004 to discharge fish at the downstream end of Cascades Island, poor egress is no longer a problem, and the B2CC is operated full time during the spring and summer emigration periods.

Since 1977, annual fish passage plans prepared by the Columbia River Water Management Group's interagency Committee on Fish Operations from 1979 to 1984 and prepared by the USACE Northwest Division's Reservoir Control Center from 1984 through 2005 (Committee on Fishery Operations 1979-1985; Reservoir Control Center 1985a,b - 2005) have dictated operations deemed necessary to protect and enhance anadromous fish species. Many of the operations are highly specific (such as chain gate adjustments at B1, gatewell or STS inspection frequencies, or the precise spill pattern for any level of spill discharge) and will not be summarized by year in this report. From 1960 until B2 was operational in 1982, spill was common and rarely planned because river flows usually greatly exceeded the discharge capacity of the single powerhouse at B1 (Figure 1.2). Most non-drought years before B2 was finished in 1982 had as high or higher percent spill than years after B2 was operational, even though spill for juvenile fish passage was not mandated until 1996 by the 1995 Biological Opinion (BiOp) of the National Marine Fisheries Service (NOAA Fisheries 1995). Project discharge has generally declined over the historical period of record, although there was a lot of year-to-year variability (Figure 1.2). From about 1960 through 1990, spill discharge and percent spill have exhibited a general downward trend, which paralleled Project discharge. The discharge estimates in Figure 1.2 are from the DART web site, and spill discharge has not been corrected to address underestimates for spill < 75,000 cfs.

Biological opinions in 1995 and 2000 called for continuous spill at Bonneville Dam during the spring and summer migrations since 1996 (NOAA Fisheries 1995 and 2000) and consisted of the following elements:

1. Spill for juvenile fish passage will begin on April 10 and end August 31. These are planning dates and are flexible according to specific requirements relating to fish abundance.
2. The daytime spill amount is 75 kcfs in order to reduce adult fallback even though this exceeded the 2000 BiOp minimum spill level of 50 kcfs.
3. At night, the spill amount will be up to the 120% gas cap.

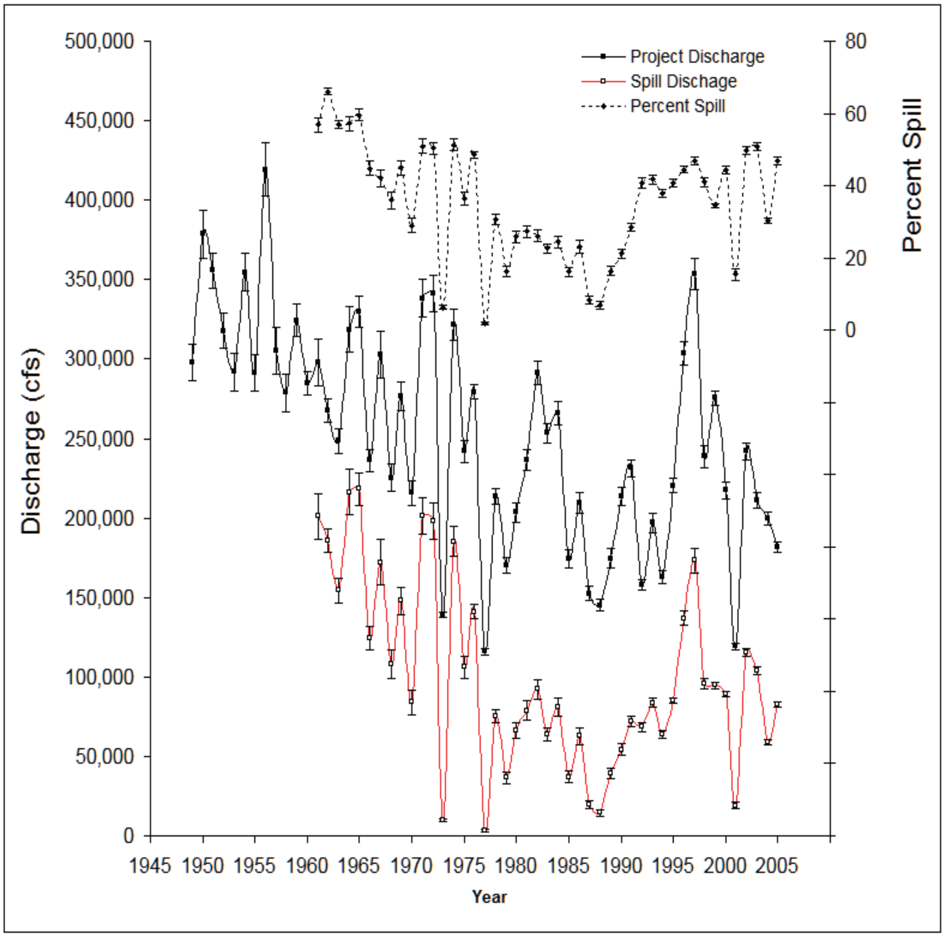

Figure 1.2. Historical Record of Percent Spill (Upper Plot) and Project and Spill Discharge Volume (Lower Plot) During the Spill Season at Bonneville Dam through 2005. Percent spill was calculated as spill discharge / total discharge for the period April 20 through August 31 each year.

After B2 came on line in 1982 and especially after fish guidance efficiency problems were identified in 1983, fish passage plans from 1984 through 2000 called for B1 to be the priority powerhouse. In general, B2 units were not operated except for research purposes unless they were needed to limit spill to 75,000 cfs during daylight hours. Units 11, 17, and 18 were the priority units in most years, after B1 units. It was not until 2001 that the fish passage plan switched the powerhouse priority from B1 to B2. This change in priority was made possible by a new switch that allowed the two powerhouses to operate independently and by new data suggesting that survival of fish passing B2 was higher than previously thought. Some managers have hypothesized that a B2 priority would produce higher spill efficiencies than a B1 priority because of smoother flows entering the spillway and B2 forebays. Research on powerhouse priorities also played an important role in the switch from B1 to B2 priority. The B2 likely will remain the priority powerhouse since the Portland District redesigned the B2 ice/trash sluice chute (ITC) outfall to discharge fish near the downstream tip of Cascades Island in winter 2003-2004, and since researchers documented very high efficiency and effectiveness for the B2CC in 2004.

Methods of research also have changed over the years. Researchers have long used nets and traps to assess fish passage, injury, and survival, and these are still used today, although perhaps not as often as remote sensing techniques like fishery hydroacoustics that were developed in the 1980s and 1990s, passive integrated transponder (PIT) tag detection developed since the 1980s, and radio telemetry, which has been used for tracking smolts since the mid 1990s. Since 2000, radio telemetry of juvenile salmonids has been used to estimate route-specific passage and survival. Acoustic telemetry, which has been used once to track fish in three dimensions in the B1 forebay in 2000 (Faber et al. 2001), likely will be more widely used in the future.

1.3 Species Composition and Run Timing

The following salmonid species migrate downstream past Bonneville Dam:

Oncorhynchus tshawytscha Chinook salmon (yearling and subyearling)
O. mykiss steelhead trout
O. nerka sockeye salmon
O. kisutch coho salmon.

Peaks in migration timing for each species of juvenile salmon may shift by 1-2 weeks depending upon the exact timing of releases from hatcheries upstream of Bonneville Dam and the magnitude of river discharge (Figures 1.3, 1.4, and 1.5). Species composition also may vary widely among years. We selected 1996 (Figure 1.3), 2001 (Figure 1.4), and 2004 (Figure 1.5) to represent very wet, very dry, and average flow conditions for the lower Columbia River, respectively. In 1996, river discharge and percent spill were both high (Figure 1.2), and the ranking of species by abundance in spring was 42% subyearling Chinook salmon, 28% coho, 15% yearling Chinook salmon, 14% steelhead, and 1% sockeye. In the drought year of 2001, river discharge and percent spill were far below average (Figure 1.4), and the ranking of species by abundance in spring was 42% coho, 30% yearling Chinook salmon, only 18% subyearling Chinook salmon, 9% steelhead, and < 1% sockeye. In 2004, when discharge and percent spill were more average (Figure 1.5), subyearling Chinook salmon again dominated the springtime species composition (46%) like they did in 1996. Yearling Chinook salmon were the second most abundant in spring 2004 (30%), followed by coho (19%), a weak run of steelhead (3%), and a relatively strong run of sockeye (2%). Subyearling Chinook salmon dominated the summer run in all years, making up 86% of all species in 1996, 63% in 2001, and 89% in 2004. Subyearlings appear to be at a disadvantage during summers of drought if 2001 was a representative drought year.

Variations in species composition among weeks in spring and among years (Figure 1.3-1.5) have important implications for acoustic and radio tagging studies and their conclusions. Neither method provides much statistical inference for the majority of juvenile salmonids migrating in spring. Only yearling Chinook salmon and steelhead were tagged in spring, and in most years those species make up < 40% of the spring run. For example, yearling Chinook salmon and steelhead only make up 29%, 40%, and 33% of the run in spring 1996, 2001, and 2004, respectively. Results of tagging studies are very useful for assessing species-specific effects of structural changes or operations, but they provide no inference for the other species or age groups that are not tagged and that, in this case, made up 61% to 71% of the spring run in most years. Tagging of subyearling Chinook salmon provides inference for the majority of the juvenile salmonids migrating in summer (> 86% of migrants in normal to wet years).

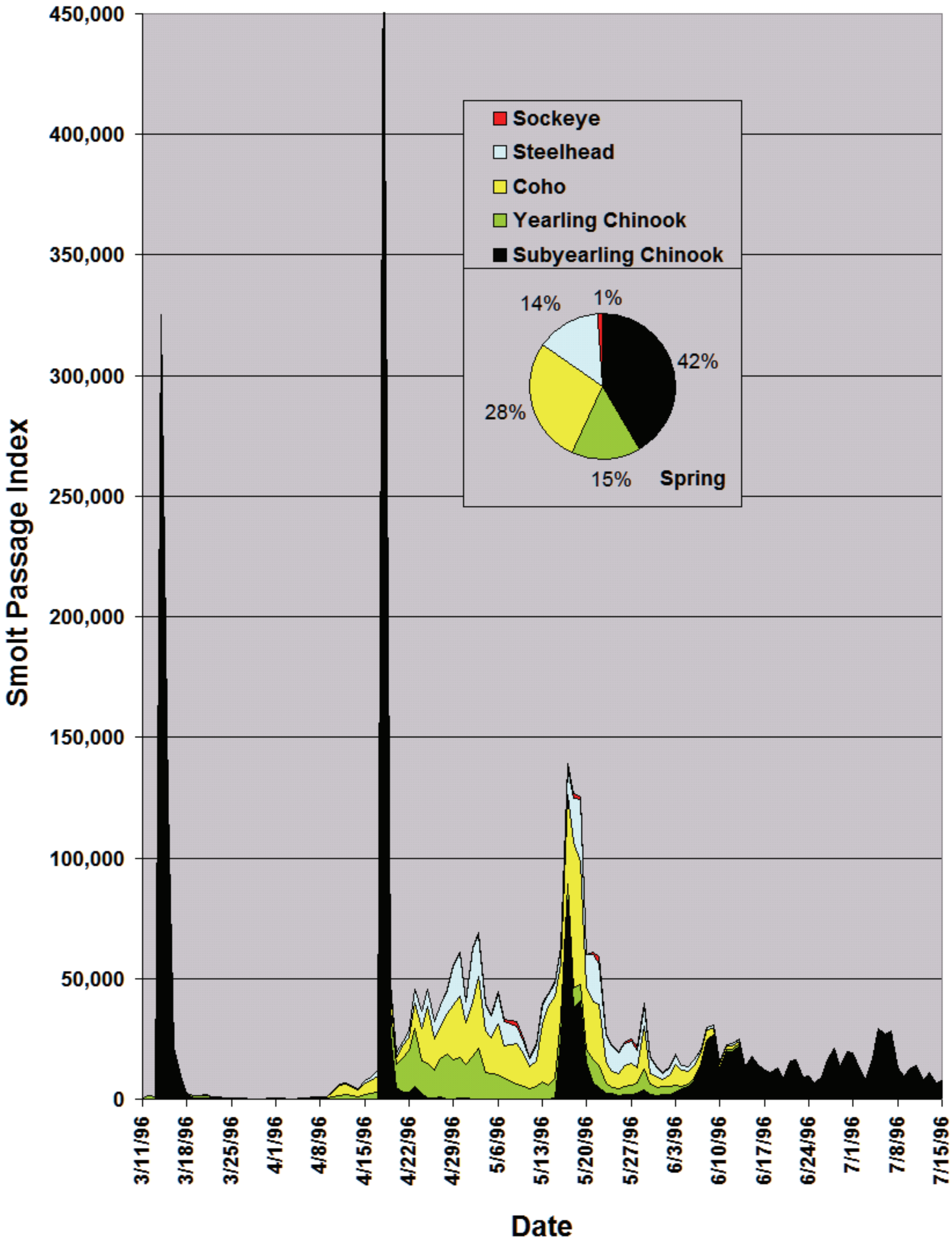

Figure 1.3. Species Composition and Run Timing based upon the Smolt Passage Index at the Bonneville Dam B1 Smolt Monitoring Facility in 1996, a Year of Above-Average Flow and Spill Discharge

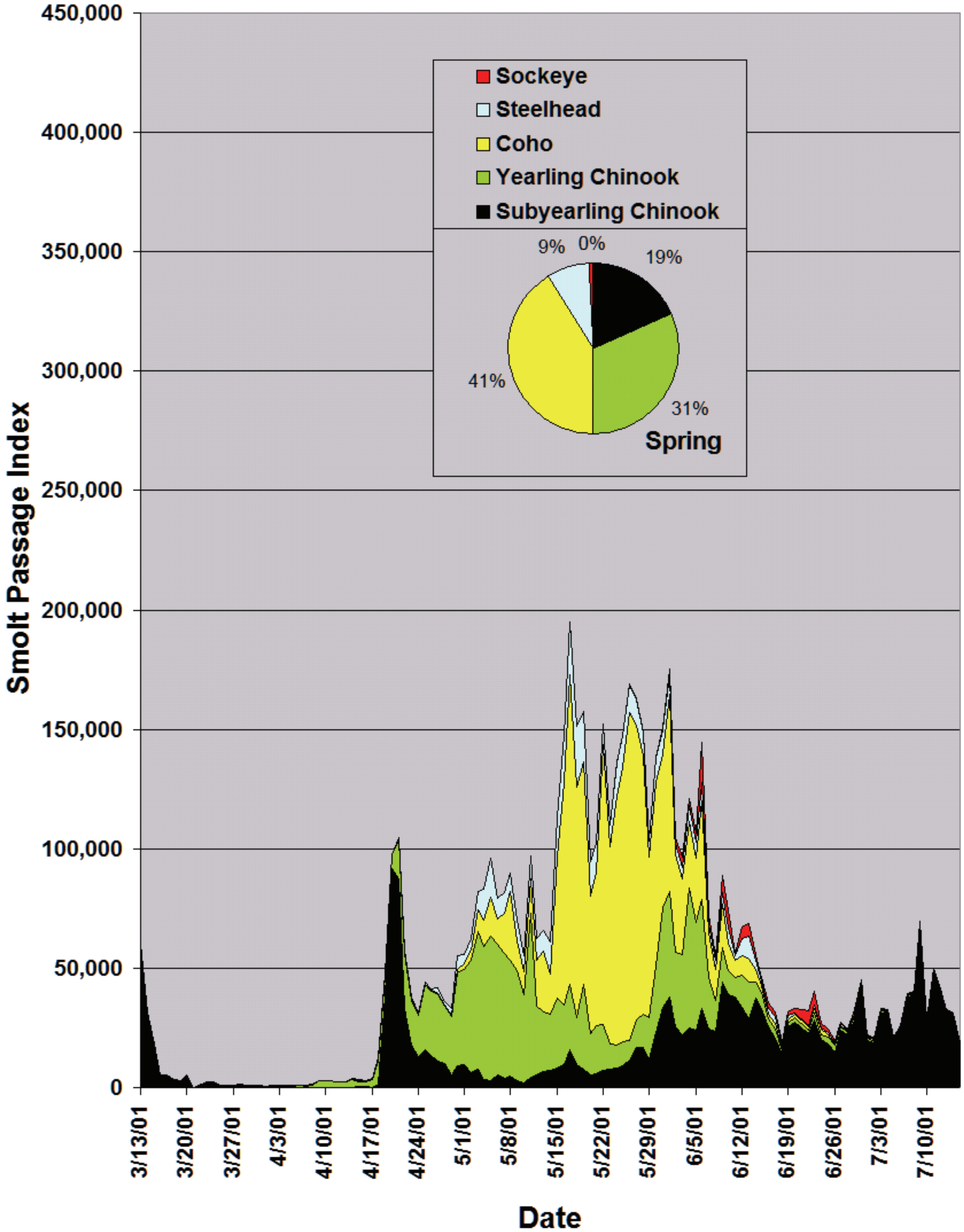

Figure 1.4. Species Composition and Run Timing based upon the Smolt Passage Index at the Bonneville Dam B2 Smolt Monitoring Facility in 2001, a Year of Below-Average Flow and Percent Spill

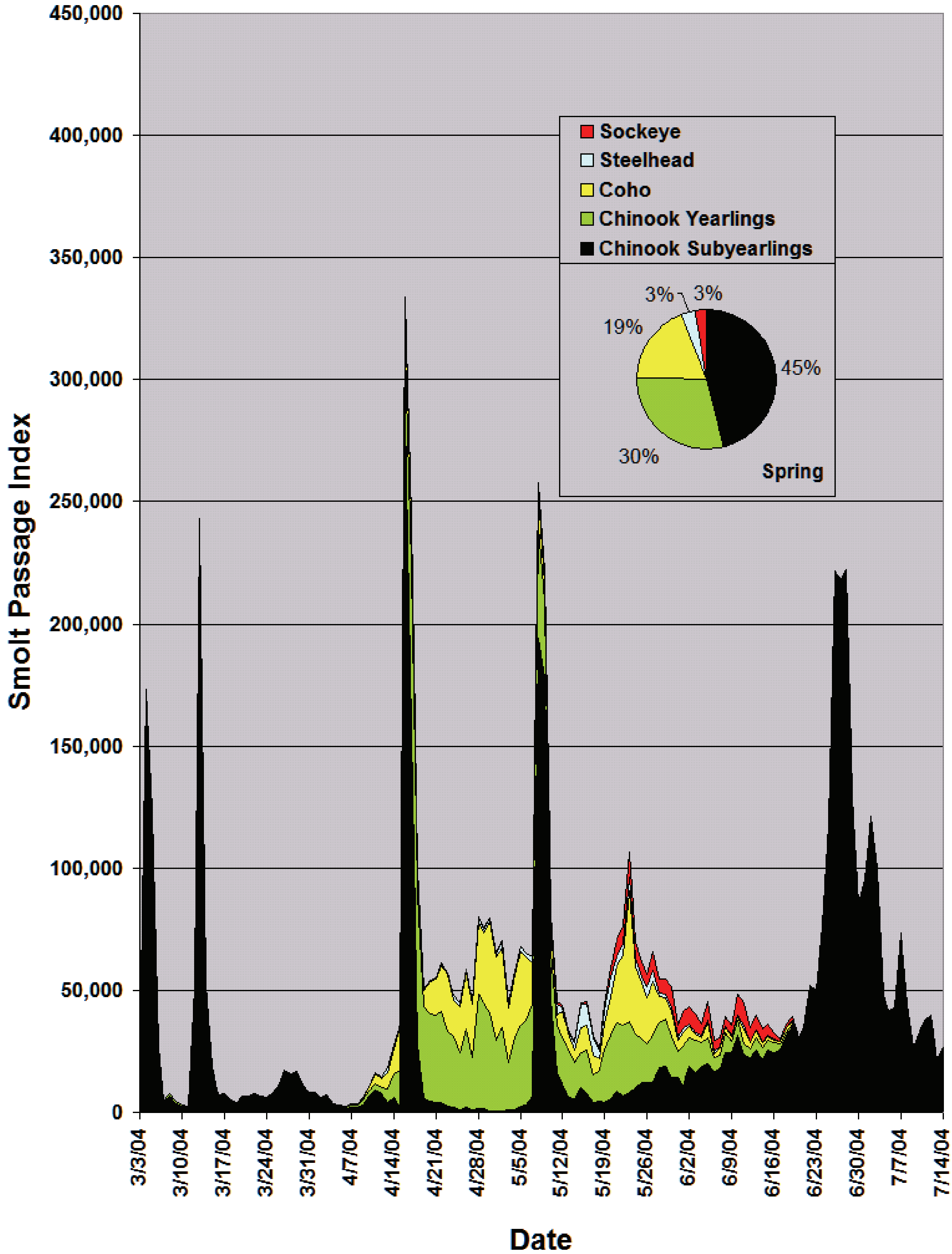

Figure 1.5. Species Composition and Run Timing based upon the Smolt Passage Index at the Bonneville Dam B2 Smolt Monitoring Facility in 2004, a Year of Average Flow and Percent Spill

1.4 Studies of Juvenile Fish Passage at Bonneville Dam 1939-2005

Each of the studies that we reviewed was assigned an identification number. Table 1.1 lists all of the reports and their corresponding ID numbers. (These reference numbers also appear in Appendix A as the hyperlinks for each report.) Table 1.2 is a comprehensive matrix indicating which reports pertain to which dam structures or topics of study and which year of dam operation from 1939 through 2005.

1.5 Overview of this Report

This report contains six chapters and two appendixes. Chapter 1 is this introduction. Chapter 2 describes fish distribution and movement in the forebays above both powerhouses and the spillway. Chapter 3 describes passage characteristics including major passage metrics, surface flow outlets, fish guidance efficiency, and the distribution of passage including horizontal, vertical, and diel distributions. Chapter 4 summarizes survival research. Chapter 5 is a synthesis and conclusions. Chapter 6 is a list of references cited in this report. Appendix A is a list of the references with hyperlinks to full PDF versions of each of the reports, which are contained on the accompanying DVD. Appendix B is an annotated bibliography which provides an abstract of each report listed in Appendix A and included on the DVD. The abstracts are provided for readers who are less familiar with the research by title. For convenience, citations with more than two authors are arranged by first author, year, and if necessary, by an assigned alphabetic letter whenever there were multiple papers per year with the same lead author, regardless of the order of the coauthors (e.g., Evans et al. 2003a,b; Evans et al. 2006a,b,c).

Table 1.1. Listing of PDF Identification Numbers and Associated Citations. Not all numbers between 1 and 182 were used because some reports were dropped before publication.

ID. No.	Citation	ID. No.	Citation
BS001	Ploskey et al. 2003	BS085	Ledgerwood et al. 1990
BS002	Normandeau et al. 2003	BS086	Gessel et al. 1990
BS003	Monk et al. 2002	BS087	Ferguson1991
BS004	Ploskey et al. 2002c	BS088	Dawley et al. 1989
BS005	Evans et al. 2001d	BS089	Gessel et al. 1989
BS006	Evans et al. 2001c	BS090	Dawley et al. 1988
BS007	BioAnalysts, ENSR, INCA. 2001	BS091	Michimoto 1971
BS008	Holmberg et al. 2001	BS092	Jensen 1987.
BS009	Monk & Sandford 2001	BS093	Nagy & Magne 1986
BS010	Wertheimer, Dalen, Madson 2001	BS094	Magne 1987a
BS011	Ploskey et al. 2002a	BS095	Krcma, Long, & Thompson 1978
BS012	Ploskey et al. 2002b	BS096	Long & Krcma 1977
BS013	Evans et al. 2001b	BS097	Long & Krcma 1977
BS014	Evans et al. 2001a	BS098	Johnson 1970
BS015	Johnson & Giorgi 1999	BS099	Michimoto & Korn 1969
BS016	Holmberg et al. 2001	BS102	Dawley et al. 1993a
BS017	Plumb et al. 2001	BS103	Holmes 1952.
BS018	Monk, Sandford, & Dey 1999	BS104	McConnell & Muir 1982
BS019	Ploskey et al. 2001a	BS105	Jones, Starke, & Stansell 1997
BS020	Hanks and Ploskey 2000	BS106	Jones, Starke, & Stansell 1999
BS021	Ploskey et al. 2000	BS107	Fisheries Eng. Res. Prog. 1957
BS022	Bickford & Skalski 2000	BS108	Jones, Starke, & Stansell 1996

BS023 Hawkes et al. 1991
BS024 BioSonics 1998
BS025 Gessel et al. 1991
BS027 Johnson et al. 2000
BS028 Gessel, Monk, & Williams 1988
BS029 Gessel et al. 1987
BS030 Johnson, Moursund, Simmons 1999
BS031 Gessel et al. 1986
BS032 Gessel et al. 1985
BS033 Krcma et al. 1984
BS035 Hensleigh et al. 1999
BS036 Holmberg et al. 1996
BS037 Evans et al. 2003a
BS038 Hansel et al. 1999
BS039 Krcma et al. 1982
BS040 Ploskey et al. 1998
BS042 Magne, Rawding, & Nagy 1986
BS043 Magne 1987b
BS044 Magne, Stansell, & Nagy 1989
BS045 Muir et al. 1989
BS047 Thorne & Kuehl 1989
BS048 Ploskey et al. 2001b
BS049 Thorne & Johnson 1993
BS050 Stansell et al. 1990
BS051 Uremovich et al. 1980
BS054 Monk, Gessel, & Ferguson 1999
BS055 Monk, Sandford, & Dey 1993
BS056 Monk, Sandford, & Dey 1995
BS062 Willis & Uremovich 1981
BS063 Mebane, Maret, & Hughes 2003
BS064 Smith et al. 2000 (1998)
BS066 Zimmerman & Ward 1999
BS067 Muir et al. 2001
BS069 NW Fisheries Science Center 2000
BS072 Zabel et al. 2001
BS073 Smith et al. 2000 (1999)
BS074 Muir et al. 2003
BS075 Giorgi & Stevenson 1995
BS077 Normandeau 2000
BS078 Nagy 1997
BS079 Ledgerwood et al. 1994
BS080 Monk et al. 1993
BS081 Gilbreath et al. 1993
BS082 Monk, Varney, & Grabowski 1992
BS083 Ledgerwood et al. 1991
BS109 Magne 1987c
BS110 Magne 1984
BS112 Bell 1971
BS114 Dawley et al. 1998
BS115 Simmons et al. 2001
BS116 Martinson et al. 1997
BS117 Monan & Liscom 1974
BS118 Gessel et al. 1994
BS119 Shrank, Dawley, & Ryan 1997
BS120 Toner, Ryan, & Dawley 1995
BS121 Toner & Dawley 1995
BS122 Gauley, Anas, Schlotterbeck 1958
BS123 Normandeau et. al. 2001
BS124 Johnson et al. 2001
BS125 Johnson & Carlson 2001
BS126 Normandeau et al. 1996
BS127 Snelling & Mattson 1996
BS128 Johnson, Giorgi, & Erho 1997
BS129 Dawley et al. 1992
BS130 Dawley et al. 1993a
BS131 Gessel et al. 1986b
BS132 Petersen, Gadomski, & Poe 1994
BS133 Dawley et al. 1991
BS134 Portland Dist. COE 2001
BS135 Ward, Petersen, & Loch 1995
BS136 Counihan et al. 2003
BS137 Evans et al. 2003b
BS139 Counihan et al. 2002
BS140 Ploskey et al. 2004
BS141 Faber et al. 2001
BS142 Monk et al. 2004
BS170 Skalski et al. 2002
BS171 Johnsen and Dawley 1974
BS172 Counihan et al. 2006a
BS173 Counihan et al. 2006b
BS174 Ploskey et al. 2005
BS175 Ploskey et al. 2006c
BS176 Adams et al. 2006
BS177 Evans et al. 2006a
BS178 Evans et al. 2006b
BS179 Reagan et al. 2006
BS180 Evans et al. 2006c
BS181 Ploskey et al. 2006a
BS182 Ploskey et al. 2006b

Table 1.2. Summary of Juvenile Fish-Passage Research at Bonneville Dam from 1939 through 2005. Identification numbers in Table 1.2 correspond to ID numbers for references listed in in Table 1.1 and to full papers on an accompanying DVD.

Area	Year																
	39	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**
B1 Forebay																	
B1 Sluiceway																	
B1 Turbines	103; 107														107	107	
B1 JBS																	
B1 STS																	
B1 ESBS																	
B1 PSC																	
B1 MGRs																	
Spillway	103; 107														107	107	
Flow Deflector Tests																	
Gas Cap Tests																	
B2 Sluice Chute																	
B2 Turbines																	
B2 STS																	
B2 JBS																	
B2 JBS Outfall Relocation																	
B2 Gatewell Improvements																	
Hydraulic Effects																	
Total Project FPE and Spill Efficiency																	
Survival	103; 107														107		
Predation																	
Forebay Approach																	
Horizontal Dist.																	
Vertical Dist.																	
Diel Dist.								122			122	122		122	122		

Table 1.2. (Cont)

Area	Year																		
	56	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**	**73**	**74**
B1 Forebay																			
B1 Sluiceway														99		91			
B1 Turbines	107																		
B1 JBS																			
B1 STS																			
B1 ESBS																			
B1 PSC																			
B1 MGRs																			
Spillway	107																171	171	
Flow Deflector Tests																	171	171	
Gas Cap Tests																			
B2 Sluice Chute																			
B2 Turbines																			
B2 STS																			
B2 JBS																			
Hydraulic Effects															98	112			
Total Project FPE and Spill Efficiency																			
Survival	107																		
Predation																			
Forebay Approach																			
Horizontal Dist.																			
Vertical Dist.																			
Diel Dist.																			

Table 1.2. (Cont')

Area	Year																	
	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
B1 Forebay																		
B1 Sluiceway						51	39 62											
B1 Turbines	97		95				39						90	47 88	86		82	79 80 102
B1 JBS		95	95				39 62	104		32	31	29	28 90	88	85	23	82	79 80 102
B1 STS							39							47 89	86		82	80
B1 VBS							39											
B1 Bar screen			95[1]															
Spillway															81 85 102 129			
B2 Forebay										110								
B2 Sluice Chute												42	43 94 109	44	50			
B2 Turbines		96							25 33 54	25 32 54	25 31 54 93	25 29 42 54	25 28 43 54 81 87 94 102 129	25 44 45 54 81 87 89 102 129	25 50 54 81 85 86 87 102 129	81 83 87 102 129		79
B2 Bar screen														89	86			
B2 STS									25 33 54	25 32 54	25 31 54 93	25 29 42 54	25 28 43 54 94 109	25 44 45 54 89	25 45 50 54 86			
B2 TIEs												29	28	89	86			
B2 VBS										32								
B2 JBS		96[2]						104	33	32	31	29	81 87 102	87 102	85 87 102	23 83 87 102 114	114 133	114
Trash-rack effects		96								32	31	29						
Effect of Lights										32			28	89	86			
Total Project FPE and Spill Efficiency																		
Survival								104					81 90 102 129	81 88 102 129	81 85 102 129	81 83 102 114 129	114 133	79 102 114
Predation						51									118[3]	132 135	135	135
Forebay Approach																		
Horizontal Dist.							39 62			110								
Vertical Dist.	97						39			321 10	31 93	29 42		89	86			
Diel Dist.		96					62				31	29			50			

[1]Small prototype bar screen near gatewell entrance
[2] Orifice passage efficiency
[3] Northern pikeminnow population estimate

Table 1.2. (Cont')

Area	Year													Reviews
	93	94	95	96	97	98	99	00	01	02	03	04	05	
B1 Forebay			21	36 40	24 35	38			5 6	37 137				
B1 Sluiceway			126	40	35			13 141	5 6	1 2 37 137			182	15 75 128 134
B1 Turbines			21	40	20	19 38	17 140	11 12 13 77 141	4 5 6 139	1 37 136 137			182	134 170
B1 MGR								77	77	136				
B1 JBS	130			116		18	140	13	5 6 139	136 37 137				134
B1 STS				40	20	19		11 12	4 5 6	1 37 137				[2]
B1 ESBS						18 19		9 11 12 115	4	1				[2]
B1 PSC						19 30 38	17 27 48	11 12 13 124 141						15 75 125 134
Spillway			126	36	24 35	38		11 13	4 5 6 139	1 2 37 136 137		174 179 180 182	175 176 182	134
Flow Deflector			126											134
Gas Effects	121	120	119											
B2 Forebay				36 40	24 35	38		13	5 6	37 137				[1]
B2 Sluice Chute			126	36 40	24 35	19 38		123						[1] 15 75 128
B2CC												181	182	[1] 7 75 128 134
B2 Turbines	55	56		40	24	19 38	17 54	11 13	3 4 5 6 139	1 37 136 137		174 179 180	175 176	[1] 25 54 134
B2 STS	55	56		40	24	19	54	11 13	4 5 6	1 37 137	140			[1] 25 54
B2 TIEs	55	56		40			54	11	4	1		174	175	[1]
B2 VBS														[1]
B2 JBS		56		116			16	8 13	5 6 139	136 37 137				[1]
B2 JBS Relocated							16	8						
Tailrace egress				127			16	8						
B2 Gatewell Improvements									3 4	1 142	140	174	175	[1] 134
Total Project FPE								11 13 182	4 5 6 182	1 37 137 177 178 182		174 179 180 182	175 176 182	183
Spill Efficiency				36	35	38	17	11 13	4 5 6	1 37 137		174 179 180	175 176 182	
Survival	130		126					77 123	139	2 136 173	171	172	173	22 67 87 102 170
Predation	135	66	66 108	66 105 127		106								
Forebay Approach			21	36 40	24 35	30 38	17 27	11 13 124	5 6	37 137				
Horizontal Dist.				36 40	24 35	19 38		11 12 13	4 5 6	1 37 137		174 179 180	175 176	
Vertical Dist.				40	24	19 30	27 48	11 12 124	4	1		174	175	
Diel Dist.			21	40	24 35	19	48	11 12 13	4 5 6	1 37 137		174 179 180	175 176	

[1] INCA Engineers, Inc. et al. (1999)
[2] Lee, R. and D. Schwartz (2003)

2.0 Fish Distribution and Movement in Forebays

2.1 Forebay Approach Patterns

Before 1995, there are no data on fish distribution and movements in the forebays of Bonneville Dam (Giorgi and Stevenson 1995). After 1995, forebay research occurred in two primary periods:

- 1995-1998: approach patterns and vertical and horizontal distributions
- 1999-present: first detection among the three main passage routes (B1, spillway, and B2), travel rates, and residence times.

Data on fish distribution and movement began to be collected in earnest in 1995 as part of the USACE Portland District's Program on Surface Flow Bypass. Forebay research to support the Surface Flow Bypass Program was undertaken in 1995-1998 using radio telemetry to determine approach paths and hydroacoustic techniques to determine vertical and horizontal distributions. The radio telemetry tool also provided data on travel rates, distribution among the three forebays, and residence times during 1995-1998. However, because of small sample sizes, these data are not as robust as radio telemetry data collected from 1999 to the present and thus are not used in favor of the latter data on those topics. Forebay migration characteristics were studied as part of the extensive radio telemetry efforts in 1999-present for the program on Total Project Fish Passage Efficiency. These research efforts provided useful data on travel rates between the upriver release locations and Bonneville Dam, distribution among the three migration routes, and forebay residence times.

2.2 Forebay Approach Patterns

In 1996, 1997, and 1998, investigators coupled data describing the location of radio-tagged smolts upstream of Boat Rock with data identifying the location where these tagged fish passed the dam (Holmberg et al. 1996; Hensleigh et al. 1999; Hansel et al. 1999). Most radio-tagged smolts moved quickly downstream to Boat Rock where they branched into the three main forebay regions of Bonneville Dam. Lateral smolt distribution on approach to Bonneville Dam influenced whether the ultimate passage route was B1, the spillway, or B2 (e.g., Hensleigh et al. 1999). Fish distributed to the south side of the channel were likely to pass the dam at B1 or the spillway (e.g., Figures 2.1 and 2.2). Fish distributed to the north side of the channel were likely to pass the dam at B2 or the spillway.

Smolt distribution in the narrow river channel between the Bridge of the Gods and Boat Rock was somewhat species-specific and always variable depending on river conditions (e.g., Hensleigh et al. 1998). Yearling Chinook salmon and steelhead were generally distributed in the southern portion of the channel (Figures 2.1 and 2.2). Subyearling Chinook salmon tended to migrate in the northern portion of the channel (Figure 2.3).

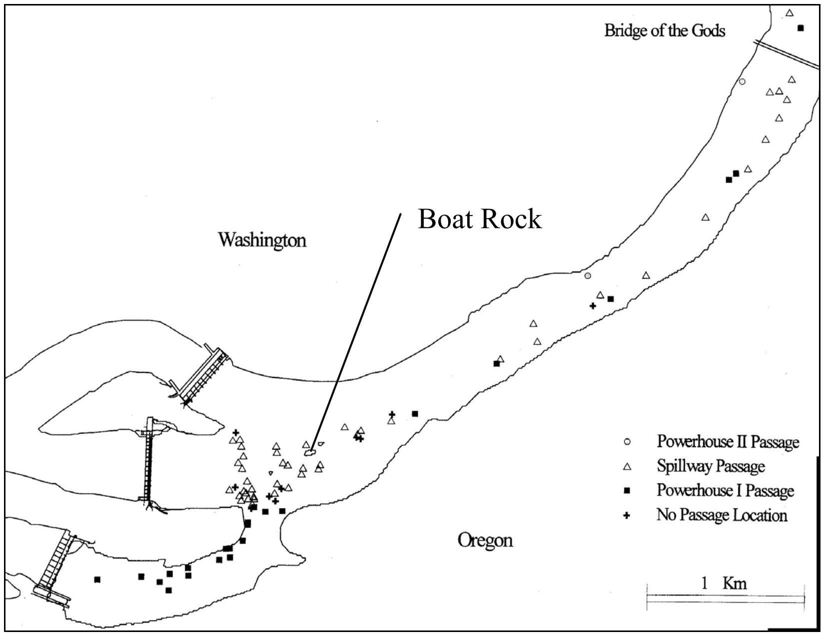

Figure 2.1. Approach Locations and Final Passage Routes of 70 Radio-Tagged Hatchery Steelhead at Bonneville Dam in Spring 1997. During the study, flows were about 80 kcfs at B1, 110 kcfs at B2, and 100-365 kcfs at the spillway. Data are from Hensleigh et al. (1999; Figure 17).

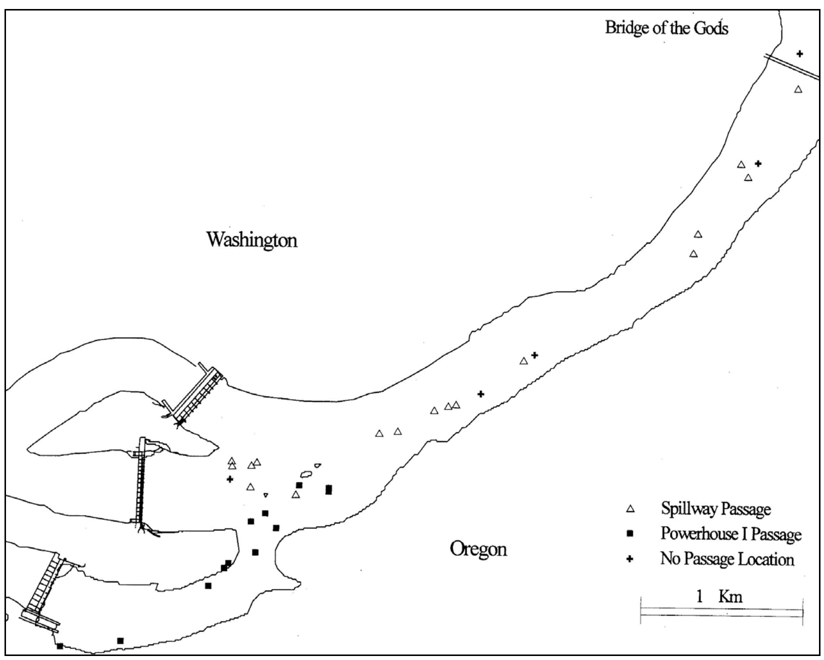

Figure 2.2. Approach Locations and Final Passage Routes of 46 Radio-Tagged Yearling Chinook Salmon at Bonneville Dam in Spring 1997. Spring 1997 flows were as described in Figure 21 of Hensleigh et al (1999). Data are from Hensleigh et al. (1999; Figure 18).

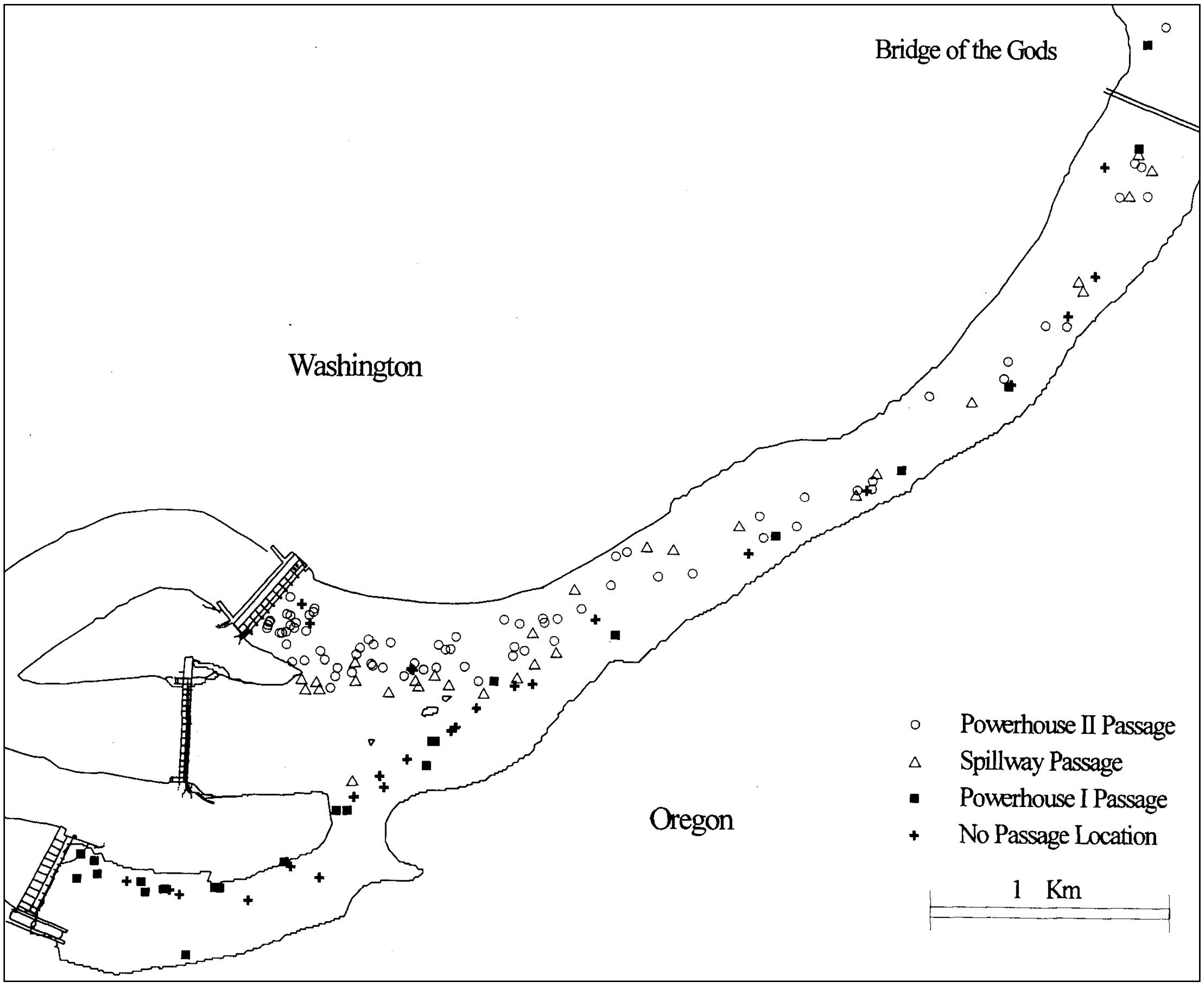

Figure 2.3. Approach Locations and Final Passage Routes of 77 Radio-Tagged Subyearling Chinook Salmon at Bonneville Dam in Summer 1997. During the study, flows were about 80 kcfs at B1, 110 kcfs at B2, and 85-120 kcfs at the spillway. Data are from Hensleigh et al. (1999; Figure 19).

2.3 Vertical Distributions

In spring and summer 1996 and 1997 at B1 and B2, researchers used mobile hydroacoustics to study forebay vertical distributions. Vertical distribution varied between B1 and B2, day and night, spring and summer, and study years (Ploskey et al. 1998 and BioSonics 1998). Vertical distribution at B1 was generally 5 to 16 ft deeper than at B2 (Table 2.1). This might be due to the deeper bathymetry at B1 than B2. Fish were distributed deeper during day than night, except during spring 1996 (Table 2.1). This is contrary to typical behavior observed at mainstem dams, which is for fish to be deeper at night than day (e.g., Thorne and Johnson 1993). Spring migrants were generally distributed deeper than summer migrants, especially in 1997 (Table 2.1).

Table 2.1. Vertical Distribution Expressed as Approximate Depth (ft) of the Uppermost 80th Percentile. Data are from mobile hydroacoustic transects 30-60 ft from the dam in spring and summer 1996 by Ploskey et al. (1998) and 1997 by BioSonics (1998).

Year	Season	Powerhouse	Day	Night
1996	Spring	B1	39	43
		B2	34	67
	Summer	B1	46	23
		B2	30	23
1997	Spring	B1	69	59
		B2	69	59
	Summer	B1	36	30
		B2	28	23

Vertical distribution can change as fish get closer to each powerhouse. Ploskey et al. (1998) noted that the depth of the 80th percentile was 6 to 17 ft shallower at transects 30 to 60 ft from B1 than at transects 150 to 225 ft from the dam. On the other hand, at B2 Ploskey et al. (1998) noticed that vertical distribution in the forebay at night got deeper the closer one got to the dam (80th percentile had a 21-ft change). They surmised this was probably due to rapid increases in forebay depth near B2 and increasing downward currents. BioSonics (1998) observed that vertical distribution shifted downward in both B1 and B2 forebays as they got closer to the powerhouses in spring 1997, but the opposite was true in summer 1997. Thus, vertical distributions changed as smolts neared the powerhouses, but this change was variable seasonally and annually with no consistent trend.

2.4 Horizontal Distributions

In 1996, Ploskey et al. (1998) studied horizontal distribution with mobile and fixed hydroacoustic surveys at both powerhouses. In 1997, BioSonics (1998) and Hensleigh et al. (1999) applied mobile hydroacoustic and radio telemetry techniques, respectively. The following horizontal distribution data reflect trends where fish were actually located at the dam. They have not been adjusted for turbine operations. Most available units at Bonneville Dam, however, were on in spring 1996 and 1997.

In 1996 at B1, baseline data on fish distributions from mobile hydroacoustics in the B1 forebay indicated that the highest average fish densities occurred upstream of units 4 through 6 in spring and upstream of units 4, 5, 6, 8, and 9 in summer (Ploskey et al. 1998). These data supported the location of a prototype surface collector in the central part of B1.

In 1997 at B1, fish tended to concentrate in the forebay of the central and northern sections of the dam (BioSonics 1998), confirming the finding by Ploskey et al. (1998). Similarly, Hensleigh et al. (1999) reported a proportionately high number of contacts of radio-tagged fish in the same region of the B1 forebay, which may reflect a concentration of fish there since residence times were short (Table 2.2).

In 1996 at B2, smolt densities were highest at the south end of the forebay (Ploskey et al. 1998). Fish passage rates were significantly higher at the sampled intakes at units 11, 12, 13, and 18 than at the others. These data indicated that the south end of the powerhouse where the sluice chute is currently located is, in general, an appropriate location for a surface bypass because of the horizontal concentration of fish there. Furthermore, they observed dense concentrations of smolts near the face of B2, suggesting that large numbers of smolts should encounter a corner collector entrance at its current location next to the powerhouse.

In 1997 at B2, fish density was high in the south eddy (BioSonics 1998), as observed by Ploskey et al. (1998) in 1996. The distribution of radio-tagged subyearling Chinook salmon in the B2 forebay in 1997 appeared to shift to the south toward the sluice chute when it was open (Hensleigh et al. 1999).

2.5 First Detections

Table 2.2 summarizes studies of first detection, travel rate, and residence times in the forebay of Bonneville Dam from 1999 to 2005. This research was extensive as thousands of yearling and subyearling Chinook salmon and steelhead were typically tagged each year during this period for the purposes of survival studies, except for 2003 when no study was conducted.

The pattern for first detection of radio-tagged fish among the three main routes (B1, spillway, B2) was dependent on project operations and discharge. In 1999-2000, 29% of the fish were first detected at B1, whereas during 2001-2005 only 4%-9% of the total passing Bonneville dam was detected first there (Table 2.2). At the spillway, 23%-57% of first detections were recorded. The highest percentages of first detections were attained at B2 (23%-71% of total first detections).

2.6 Travel Rates

Travel rates from the release sites upstream at John Day and The Dalles dams were comparable among the three species outfitted with radio transmitters (Table 2.2). The ranges for the median rates of the annual studies were 1.8-2.7, 2.5-2.8, and 1.5-2.3 km/h for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively.

2.7 Residence Times

Forebay residence time was typically an order of magnitude longer at B1 than at either the spillway or B2 (Table 2.2). In the B1 forebay, residence times ranged from 0.9 to 9.7 h depending on species and study-year. In the spillway forebay, the range was 0.03-1.3 h. In the B2 forebay, tagged fish resided for 0.1 to 3.9 h, except for the 6.4 h observed for steelhead in 2000.

Table 2.2. Fish Distribution, Travel Rate, and Residence Times in the Forebay of Bonneville Dam from 1999 to 2004. Studies were not conducted in 2003. Steelhead smolts were not tagged in 2001. Chinook salmon subyearlings were not tagged in 1999.

Year	Study Period	Species	Mean Length (mm)	# Tagged	First Detection (%)			Travel Rate (km/h)	Forebay Residence Time (h)			Source
					B1	Spillway	B2		B1	Spillway	B2	
1999	5/1-6/10	CH1	163	1,106	29	39	32		1.1	0.1	0.2	a
2000	4/25-6/6	CH1	155	2,075	29	48	23	2.7	3.4	0.1	1.3	b
2001	5/1-6/9	CH1	157	1,211	6	23	71	1.8	2.7	0.3	0.2	c
2002	5/2-6/9	CH1	149	2,382	9	57	34	2.1-2.4	2.5	0.03	1.3	d
2004	4/27-6/2	CH1	157	6,716	8	33	59	2.4-2.5	0.9	0.3	0.1	e
2005	4/29-6/6	CH1	154	5,820	4	32	64	2.5	2.7	0.4	0.1	f
1999	5/1-6/10	ST	215	779	38	35	27		5.6	0.3	3.9	a
2000	4/25-6/6	ST	222	1,193	35	36	19	2.8	9.7	0.5	6.4	b
2002	5/2-6/9	ST	188	792	7	57	36	2.5	2.4	0.1	2.0	d
2004	4/27-6/2	ST	224	4,399	8	26	35	2.5	4.2	0.3	2.0	e
2005	4/29-6/6	ST	221	4,278	3	33	64	2.7	5.2	0.5	0.6	f
2000	6/20-7/24	CH0	126	1,188	45	36	19	2.3	1.8	0.1	2.1	g
2001	7/1-7/24	CH0	122	647	9	24	67	1.5	2.4	1.3	0.6	h
2002	6/21-7/25	CH0	117	3,357	15	28	57	2.1-2.5	1.8	0.05	1.1	i
2004	6/21-8/4	CH0	116	11,683	5	35	60	2.0-2.1	5.7	2	2.1	j
2005	6/15-7/25	CH0	108	6,525	2	48	50	2.2-2.3	4.4	0.4	0.2	f

a Plumb et al. 2001
b Evans et al. 2001a
c Evans et al. 2001c
d Evans et al. 2003a 2006a
e Reagan et al. 2006
f Adams et al. 2006
g Evans et al. 2001b
h Evans et al. 2001c
i Evans et al. 2003b 2006b
j Evans et al. 2006c

2.8 Synthesis and Conclusions

Two new metrics were developed to synthesize data on forebay migration characteristics: Bulk Flow Effectiveness and Movement Among Areas.

Bulk Flow Effectiveness is the proportion of first detections for a given area (B1, Spill, or B2) divided by the proportion of water discharged at that area. Values near 1 indicate radio-tagged fish were following the bulk flow into that particular area. Values less than 1 indicate radio-tagged fish were not following bulk flow. Values greater than 1 indicate fish might have been attracted to the bulk flow. Bulk flow effectiveness data is plotted in Figure 2.4 for studies conducted between 1999 and 2005.

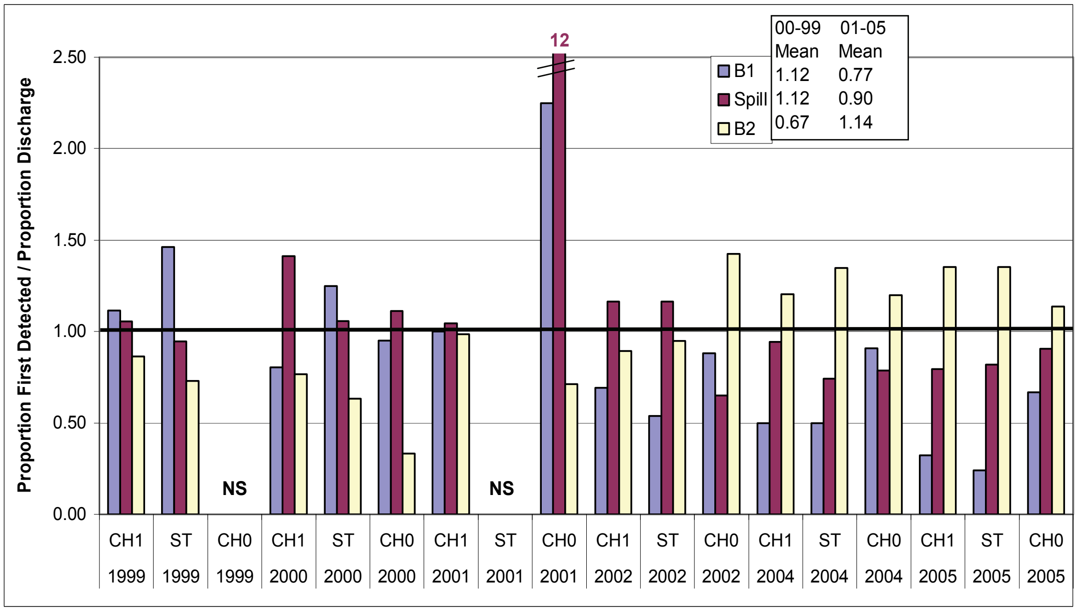

Figure 2.4. Bulk Flow Effectiveness for Bonneville Dam 1st and 2nd Powerhouse and Spillway Plotted from 1999 to 2005 Data

Movement between Areas Indicator is the proportion of first detections for a given area (B1, Spill, or B2) divided by the proportion of fish that passed at that area. Values near 1 indicate radio-tagged fish were staying in a particular area once they entered it. Values less than 1 indicate some of the radio-tagged fish moved to that particular area to pass the dam. Values greater than 1 indicate some of the fish moved out of that particular area to pass the dam. Data on movement between areas (B1, B2, and Spillway) is charted in Figure 2.5, and means near 1 indicate that movement from one area to another is low.

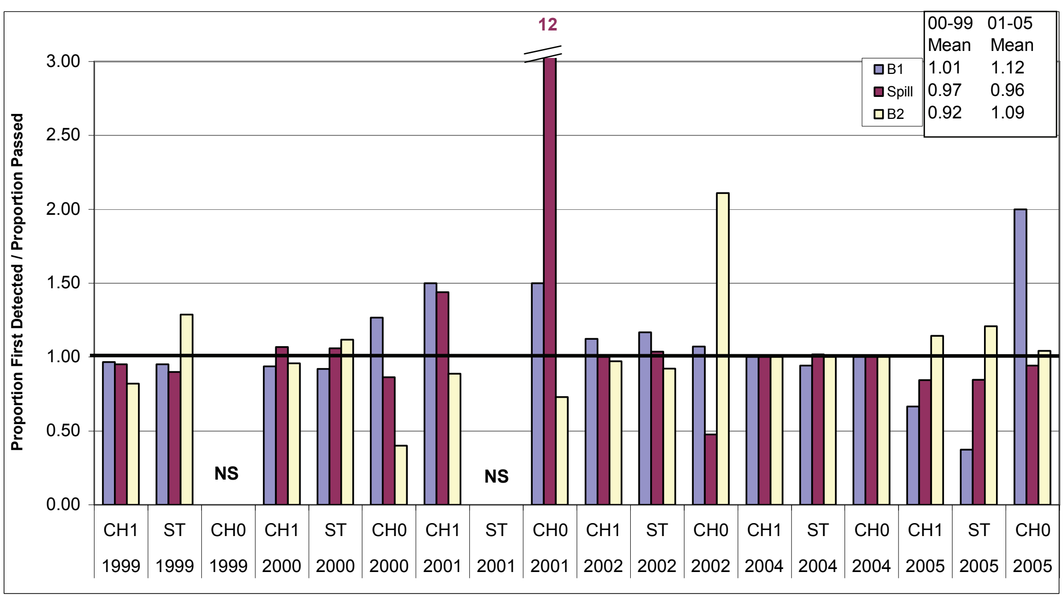

Figure 2.5. Movement between Areas Data for Bonneville Dam 1st and 2nd Powerhouse and Spillway Plotted from 1999-2005 Data

- Fish approach the dam following bulk flow, and the split in fish passage is correlated with the split in discharge among the corresponding structures. Therefore, dam operations affect fish movements in the forebay and where they subsequently pass the dam.

- Vertical distributions of fish upstream of dam structures are highly skewed toward the water's surface and, therefore, surface flow bypasses have the potential to be efficient and effective.

- Horizontal distribution in the forebays of the two powerhouses revealed areas of concentration. At B1, these areas of concentration were upstream of Units 4-6 in spring and upstream of units 4, 5, 6, 8, and 9 in summer. At B2, fish concentrated primarily at the south end of the forebay near or in a large eddy and in a smaller eddy on the north side of the forebay.

- Average travel rates (km / hours) from release sites to the project were relatively quick:

Species / Age Class	Travel Rate
Yearling Chinook salmon	2.3
Steelhead	2.6
Subyearling Chinook salmon	2.1

- Average hourly residence times in forebays were short except for B1 when B2 had the generation priority:

Species / Age Class	B1	Spillway	B2
Yearling Chinook salmon	2.2	0.2	0.5
Steelhead	5.4	0.3	3.0
Subyearling Chinook salmon	4.4	0.4	0.2

3.0 Juvenile Salmonid Passage

Section 3.1 of this chapter describes factors that control project operations and affect major fish passage metrics at Bonneville Dam. Section 3.2 describes project-wide fish-passage metrics, as estimated by fixed-aspect hydroacoustic and radio-telemetry methods. The approach was to tabulate estimates of all major passage metrics by method and then to describe effects in subsections. Under Section 3.2, we examine detailed effects of flow distributions among routes on spillway efficiency (Subsection 3.2.1), spillway effectiveness (Subsection 3.2.2), powerhouse passage proportions (3.23), surface-passage outlet efficiency and effectiveness (3.2.4), and fish-passage efficiency (3.2.5). Section 3.2 relies exclusively on five years of project-wide study, conducted from 2000 through 2005 (excluding 2003). Remaining sections of this chapter review studies on surface-flow outlets (Section 3.3), fish-guidance efficiency (3.4), and fine-scale passage distribution studies including horizontal, vertical, and diel distribution (3.5).

3.1 Project Operations and Fish Passage

During any year or passage season, there are predictable and unpredictable circumstances that affect the passage of fish at a hydropower project. Water availability and demand for electricity are of prime importance and cannot be rigorously controlled. Project operations, such as spill level or powerhouse priority, may be dictated by policies or experimental designs aimed at elucidating patterns in fish passage under different operating regimes. In addition, equipment issues, such as turbine outages, are important in determining operating regimes. Operations are more flexible at average or below-average river flows and diminish as river flow approaches flood stage.

During the five years (2000-2005, excluding 2003) of the Total Project Fish Passage Efficiency Study, there were a variety of hydrologic conditions, power demands, and experimental circumstances that have complicated the understanding of fish passage. In 2000, B1 was given generation priority while a prototype surface collector (PSC) installed across 18 intakes of Units 1 through 6 was evaluated. After 2000, there was no PSC and power generation priority was switched to B2. There was a drought and high demand for electricity from outside the region in 2001, and this resulted in severely restricted spill, both in level and duration. During 2001, the spill discharge (around 50 kcfs) did not vary with time of day (i.e., higher spill at night) as is normally the case. The following year, 2002, was a fairly high water year. During that year, three different spill levels (two in daytime and one at night) were tested. The gatewell slots of Unit 15 were modified for 2001 and those of Unit 17 were modified for 2002, and modifications to increase flow up submerged traveling screens and FGE were present thereafter. In some years, specific turbine units were operated to facilitate netting, including netting for intake modification tests at B2.

In 1996 and 1998, the B2 sluice chute was tested as a fish-passage route and was opened or closed according to a prescribed sampling design. In many other years it was opened to pass trash. In 2004, the B2 sluiceway channel was modified as the B2 Corner Collector to route water from the forebay to the downstream tip of Cascades Island, and it operated all spring and summer of 2004 and 2005, unlike earlier years when it operated rarely. During B2CC operations in 2004, TIEs were not installed at units 11-14 on the south half of B2 to increase lateral flow toward the south and the B2CC, a major departure from previous operations. In 2005, the configuration of the project was similar to that in 2004, except that B1 sluiceway gates 1C, 3C, and 6C were opened and sampled whereas in 2004 gates 2C, 4C, and 6C were opened and were sampled. All of these factors make comparisons across passage years difficult but some generalizations are possible that provide insight regarding future study needs and operational/design modifications to improve passage conditions for juvenile salmon and steelhead.

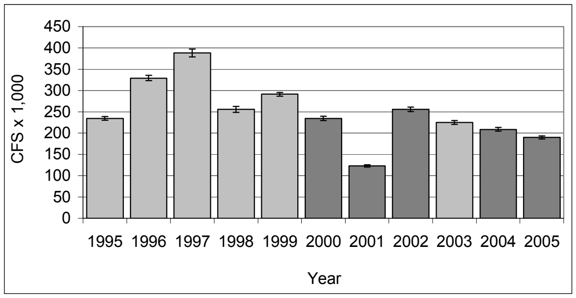

Figure 3.1. Total Discharge from The Dalles Dam, which Constitutes Most Inflow to the Bonneville Dam Project, for the Last Ten Fish Passage Seasons (April through July). (Data are from Data Access in Real Time http://www.cbr.washington.edu/dart/). Dark gray bars indicate years with Project fish-passage efficiency estimates.

3.2 Project-Wide Passage Metrics

We did not truncate sampling seasons for hydroacoustic or radio-telemetry studies so that estimates of passage metrics would be for the same periods of time. We also did not pool species-specific radio telemetry estimates to make comparisons with run-of-river (non-species specific) hydroacoustic estimates. Those truncated and smoothed comparisons are available for 2001 (Ploskey et al. 2002c; Evans 2001c; Evans 2001d), 2002 (Evans et al. 2003a and 2006a), 2004 (Evans et al. 2006c; Reagan et al. 2006), and 2005 (Ploskey et al. 2006c; Adams et al. 2006). A direct comparison of the hydroacoustic estimates and radio telemetry estimates can help to better understand the strengths and weaknesses of each method. This insight may be used to develop more accurate passage estimates in the future. These comparisons are useful to see how well the methods compare, but not for much else, because the exercise throws out a lot of data to match the sampling seasons and applies weighting factors that are incomplete because they cannot account for untagged species in the run at large. Pooling steelhead and yearling Chinook salmon estimates gives up the species-specific estimates that represent a strength of radio telemetry. Readers should remember that estimates by the two methods are based upon samples of different populations in spring. Differences in estimates may result from differences in sampled species composition in spring, temporal differences in either season, and bias, which is independent of the precision of estimates. Bias is much more insidious than lack of precision because it is very difficult to identify or quantify without detailed and very accurate information about detectability. However, for the most part, estimates comport fairly well for radically different methods that did not sample the same composition of fish.

Because of the variety of fish-passage routes associated with Bonneville Dam, a correspondingly large number of passage metrics have been developed to measure the efficiency and effectiveness for passing juvenile salmonids. Definitions of all metrics used in this chapter are presented in Table 3.1.

Table 3.1. Definitions of Major Fish-Passage Metrics. Efficiency and effectiveness metrics are relative to the entire project unless a subscript indicates otherwise. Names of individual variables are underlined when used in equations to avoid term confusion.

Definition
Project passage = (Spillway + B1 Sluiceway + B2CC + B1 Guided + B1 Unguided + B2 Guided + B2 Unguided) Variable names refer to the route of passage. The B2CC is the B2 Corner Collector, which was first opened in 2004. Guided fish are screened from turbine intakes and routed to a juvenile bypass system (JBS) channel. Unguided fish passed through turbines. Variables may be zero if a route was not open in a specific year.
Spillway efficiency = (Spillway ÷ Project passage) × 100. Spillway efficiency is the percent of Project passage through the spillway.
Fish-passage efficiency = [(Spillway + B1 Sluiceway + B2CC + B1 Guided + B2 Guided) ÷ Project passage] × 100. Fish-passage efficiency (FPE) is the percentage of fish passing the Project by non-turbine routes. Variables may be zero if a route was not open.
Fish-passage efficiency$_{B1}$ = [(B1 Sluiceway + B1 Guided) ÷ (B1 Sluiceway + B1 Guided + B1 Unguided)] × 100. Fish-passage efficiency$_{B1}$ (FPE $_{B1}$) is the percentage of fish passing B1 by non-turbine routes. Guided and Unguided terms do not apply when in-turbine screens were not deployed, as in 2004 and 2005, when this metric was equivalent to B1 Sluiceway Efficiency$_{B1}$. If the sluiceway was not sampled, this metric equals fish-guidance efficiency$_{B1}$.
Fish-guidance efficiency$_{B1}$ = [B1 Guided) ÷ (B1 Guided + B1 Unguided)] × 100. Fish-guidance efficiency$_{B1}$ (FGE$_{B1}$) is the percentage of fish in B1 turbines that were intercepted by intake screens and routed to the B1 JBS channel.
Fish-guidance efficiency$_{B2}$ = [B2 Guided) ÷ (B2 Guided + B2 Unguided)] × 100. Fish-guidance efficiency$_{B2}$ (FGE$_{B2}$) is the percentage of fish in B2 turbines that were intercepted by intake screens and routed to the B2 JBS channel.
Fish-passage efficiency$_{B2}$ = [(B2CC + B2 Guided) ÷ (B2CC + B2 Guided + B2 Unguided)] × 100. Fish-passage efficiency$_{B2}$ (B2 FPE) is the percentage of fish passing B2 by non-turbine routes. If the B2CC was not operational, this metric equals FGE$_{B2}$ (above).
Fish-passage efficiency$_{B2\ \&\ Spillway}$ = [(Spillway + B2CC + B2 Guided) ÷ (Spillway + B2CC + B2 Guided + B2 Unguided)] × 100. Fish-passage efficiency$_{B2\ \&\ Spillway}$ is the percentage of fish passing B2 and the spillway by non-turbine routes. This metric ignores B1 passage, which was low from 2001 through 2005 because of an assigned B2 generation priority.
SFO efficiency = (B1 Sluiceway + B2CC) ÷ Project passage × 100. Surface-flow-outlet efficiency (SFO efficiency) is the percentage of fish passing the project through surface flow outlets, including B1 sluiceway and B2CC.
B1 sluiceway efficiency = B1 Sluiceway ÷ Project passage × 100. B1 Sluiceway efficiency is the percent of fish passing the project through the B1 sluiceway.
B1 sluiceway efficiency$_{B1}$ = [B1 Sluiceway ÷ (B1 Sluiceway + B1 Guided + B1 Unguided)] × 100. B1 sluiceway efficiency$_{B1}$ is the percentage of fish passing B1 through the B1 sluiceway. This is the same as B1 FPE when no screens were deployed in turbines (2004 and 2005).
B2CC efficiency = B2CC ÷ Project passage × 100. B2CC efficiency is the percentage of fish passing the Project by the B2CC.
B2CC efficiency$_{B2}$ = [B2CC ÷ (B2CC + B2 Guided + B2 Unguided)] × 100 B2CC efficiency$_{B2}$ is the percentage of fish passing B2 through the B2CC after 2003.
Spillway effectiveness = Spillway efficiency ÷ Percent Spill Spillway effectiveness is the ratio of spillway efficiency to the percent of Project discharge through the spillway.
SFO effectiveness = *SFO* efficiency ÷ Percent SFO Flow Surface-flow-outlet effectiveness (SFO effectiveness) is the ratio of percent fish passage through surface flow outlets to the percent of Project flow through the same outlets (Percent SFO Flow).
B1 sluiceway effectiveness = B1 Sluiceway efficiency ÷ Percent B1 sluiceway Flow B1 sluiceway effectiveness is the ratio of the percentage of fish to the percentage of flow passing the Project through the B1 sluiceway.
B1 sluiceway effectiveness$_{B1}$ = B1 sluiceway efficiency$_{B1}$ ÷ Percent B1 sluiceway flow$_{B1}$ B1 sluiceway effectiveness$_{B1}$ is the ratio of the percentage of fish to the percentage of flow passing B1 through the B1 sluiceway.
B2CC effectiveness = *B2CC Efficiency* ÷ Percent B2CC Flow B2CC effectiveness is the ratio of the percentage of fish to the percentage of flow passing the Project through the B2CC.
B2CC effectiveness$_{B2}$ = B2CC Efficiency$_{B2}$ ÷ Percent B2CC Flow$_{B2}$ B2CC effectiveness$_{B2}$ is the ratio of the percentage of fish to the percentage of flow passing B2 through the B2CC.

In 2006, Ploskey et al. (2006b) re-analyzed the five years of project-wide hydroacoustic data and compiled estimates of all major fish passage metrics for spring and summer in Tables (Tables 3.2 and 3.3), and Adams et al. (2006) compiled the estimates based upon radio telemetry (Tables 3.4 and 3.5).

Table 3.2. Estimates of Major Flow and Passage Metrics ± ½ 95% Confidence Limits for Spring Based upon Hydroacoustic Sampling in 2000, 2001, 2002, 2004, and 2005. Headings list some important differences in conditions or sampling methods among years. STS = submerged traveling screen. After a table in Ploskey et al. (2006b).

Major Passage Metric	2000 PSC at Units 1-6 B1 Priority No Sluiceway Sampled; No STS in PSC Screens in 7-10	2001 Severe Drought B2 Priority No Sluiceway Sampled; B1 Screens Installed	2002 B2 Priority B1 Sluiceway Sampled; B1 Screens Installed	2004 B2 Priority B1 Sluiceway & B2CC Sampled No B1 Screens	2005 B2 Priority B1 Sluiceway & B2CC Sampled No B1 Screens
Dates Sampled	4/20 – 6/01	4/20 – 6/05	4/20 – 6/02	4/15 – 5/31	4/16 – 5/31
B1 Percent of Project Flow	37.8%	7.5%	12.3%	12.6%	11.6%
B1 Percent of Project Passage	33.2%	6.8%	17.9%	16.8 ± 0.9%	16.3 ± 0.6%
Spillway Percent of Project Flow	31.5%	14.7%	44.6%	33.5%	40.3%
Spillway Efficiency	47 ± 0.1%	15.0 ± 0.2%	54.0 ± 0.5%	41.2 ± 0.9%	39.7 ± 1.1%
B2 Percent of Project Flow	32.1%	78.2%	42.6%	51%	48.2%
B2 Percent of Project Passage	20.3%	78.5%	27.9%	42.0 ± 1.2%	44.1 ± 1.6%
Fish-Passage Efficiency	80 ± 0.1%	63 ± 0.3%	79 ± 0.1%	74 ± 1.2%	73.4 ± 2.0%
Fish-passage efficiency$_{B1}$	67 ± 0.1%	49 ± 2.3%	58 ± 0.4%	33.3 ± 2.0%	37.4± 0.8%
Fish-guidance efficiency$_{B1}$	54 ± 0.1%	49 ± 2.3%	37 ± 0.4%	N/A	N/A
Fish-guidance efficiency$_{B2}$	55 ± 0.1%	57 ± 0.3%	53 ± 0.3%	48 ± 3.3%	45.0 ± 4.3%
Fish-passage efficiency$_{B2}$	55 ± 0.1%	57 ± 0.3%	53 ± 0.3%	64.0 ± 2.1%	62.8 ± 3.9%
Fish-passage efficiency$_{B2\ \&\ Spillway}$	N/A (B1 Priority)	64 ± 0.3%	84 ± 0.1%	82 ± 0.01%	80.4 ± 0.1%
% of Project flow through surface flow outlets	N/A	N/A	0.03	3.3%	3.2%
Surface-flow-outlet efficiency	N/A	N/A	6.0 ± 0.1%	18.8 ± 0.4%	20.2 ± 0.6%
B1 Sluiceway efficiency	N/A	N/A	5.9	5.6 ± 0.1%	6.08 ± 0.2%
B1 sluiceway efficiency$_{B1}$	N/A	N/A	33.2 ± 0.9%	33.3 ± 2.0%	37.4 ± 0.8%
B2CC efficiency	N/A	N/A	N/A	13.2 ± 0.3%	14.1 ± 0.4%
B2CC efficiency$_{B2}$	N/A	N/A	N/A	31.4 ± 1.4%	31.9 ± 2.0%
Spillway effectiveness	1.49 ± 0.01	1.02 ± 0.00	1.21 ± 0.01	1.13 ± 0.03	0.98 ± 0.03
Surface-flow-outlet effectiveness	N/A	N/A	19.7 ± 0.01	5.7 ± 0.12	6.3 ± 0.18
B1 sluiceway effectiveness	N/A	N/A	19.7 ± 0.01	10.1 ± 0.23	10.7 ± 0.3
B1 sluiceway effectiveness$_{B1}$	N/A	N/A	13.5 ± 0.06	7.6 ± 0.5	7.6 ± 0.2
B2CC effectiveness	N/A	N/A	N/A	4.8 ± 0.1	5.3 ± 0.2
B2CC effectiveness$_{B2}$	N/A	N/A	N/A	5.8 ± 0.03	5.8 ± 0.4

Table 3.3. Estimates of Major Flow and Passage Metrics ± ½ 95% Confidence Limits for Summer Based on Hydroacoustic Sampling in 2000, 2001, 2002, 2004, and 2005. Headings list some important differences in conditions or sampling methods among years. After a table in Ploskey et al. (2006b). STS = submerged traveling screen.

Major Metric	2000 PSC at Units 1-6 B1 Priority No Sluiceway Sampled; No STS in PSC Screens in 7-10	2001 Severe Drought B2 Priority No Sluiceway Sampled; B1 Screens Installed	2002 B2 Priority B1 Sluiceway Sampled; B1 Screens Installed	2004 B2 Priority B1 Sluiceway & B2CC Sampled No B1 Screens	2005 B2 Priority B1 Sluiceway & B2CC Sampled No B1 Screens
Dates Sampled	06/05 – 07/15	06/06 – 7/15	6/03 – 7/15	6/05 – 7/15	6/02 – 7/15
B1 Percent of Project Flow	48.9%	8.7%	22.0%	13.5%	3.7%
B1 Percent of Project Passage	40.9%	7.4%	34.7%	15.8%	7.2 ± 0.3%
Spillway Percent of Project Flow	43%	9.8%	40.2%	33.5%	51.6%
Spillway Efficiency	52.0 ± 0.2%	22.0 ± 0.3%	45.0 ± 0.6%	34.1 ± 0.7%	44.2 ± 1.3%
B2 Percent of Project Flow	10.1%	81.7%	37.2	53.0%	44.8%
B2 Percent of Project Passage	6.8%	71.0%	19.8%	50.1 ± 0.4%	48.6 ± 1.5%
Fish-Passage Efficiency	80 ± 0.1%	54 ± 0.4%	76 ± 0.2%	71 ± 1.2%	81 ± 2.1%
Fish-passage efficiency$_{B1}$	61 ± 0.1%	40 ± 1.8%	61 ± 0.3%	37.6 ± 1.5%	70.9 ± 1.3%
Fish-guidance efficiency$_{B1}$	39 ± 0.1%	40 ± 1.8%	45 ± 0.5%	0 (No STSs)	0 (No STSs)
Fish-guidance efficiency$_{B2}$	35 ± 1%	42 ± 0.4%	46 ± 0.1%	36 ± 2.9%	37 ± 4.4%
Fish-passage efficiency$_{B2}$	35 ± 1%	42 ± 0.4%	46 ± 0.1%	61 ± 2.0%	64.6 ± 3.5%
Fish-passage efficiency$_{B2\ \&\ Spillway}$	N/A (B2 Priority)	55 ± 0.4%	84 ± 0.5%	77 ± 0.02%	82 ± 0.02%
% of Project flow through surface flow outlets	N/A	N/A	0.24	3.3%	3.5%
Surface-flow-outlet efficiency	N/A	N/A	10.0 ± 0.1%	25.8 ± 0.5%	26.2 ± 0.7%
B1 Sluiceway efficiency	N/A	N/A	10.0 ± 0.1%	5.9 ± 0.1%	5.13 ± 0.2%
B1 sluiceway efficiency$_{B1}$	N/A	N/A	29.1 ± 0.7%	37.6 ± 1.5%	70.9 ± 1.2%
B2CC efficiency	N/A	N/A	N/A	19.9 ± 0.4%	21.1 ± 0.6%
B2CC efficiency$_{B2}$	N/A	N/A	N/A	39.6 ± 1.5%	43.5 ± 2.5%
Spillway effectiveness	1.21 ± 0.01	2.25 ± 0.01	1.12 ± 0.01	1.02 ± 0.02	0.86 ± 0.03
Surface-flow-outlet effectiveness	N/A	N/A	42.8 ± 0.03	7.9 ± 0.15	7.60 ± 0.22
B1 sluiceway effectiveness	N/A	N/A	42.8 ± 0.03	10.9 ± 0.2	8.6 ± 0.3
B1 sluiceway effectiveness$_{B1}$	N/A	N/A	26.9 ± 6.6	9.3 ± 0.4	4.3 ± 0.08
B2CC effectiveness	N/A	N/A	N/A	7.3 ± 0.14	7.4 ± 0.21
B2CC effectiveness$_{B2}$	N/A	`N/A	N/A	7.7 ± 0.28	6.8 ± 0.4

Table 3.4. Passage Performance Metrics for Yearling Chinook Salmon and Steelhead at Bonneville Dam during Spring Study Periods in 2000, 2001, 2002, 2004, and 2005 based on Radio Telemetry. B1 = first powerhouse and B2 = second powerhouse. Adapted from a table by Adams et al. (2006)

Species and Passage Metric	2000	2001	2002	2004	2005
Dates Sampled	4/25-6/6	5/1-6/9	5/2-6/9	4/29-6/7	5/1-6/12
Yearling Chinook Salmon					
Spillway Percent of Project Flow	34%	22%	49%	35%	40.3
Spillway efficiency	44%	16%	57%	33%	37%
Spillway effectiveness	1.3	0.7	1.2	0.9	0.9
Fish-guidance efficiency$_{B1}$	50%	45%	50%	a	a
Fish-guidance efficiency$_{B2}$	39%	46%	37%	33%	36%
Fish passage efficiency	73%	56%	76%	71%	71%
Fish-passage efficiency$_{B1}$	65%	87%	69%	54%	35%
Fish-passage efficiency$_{B2}$	39%	46%	37%	57%	55%
B1 sluiceway efficiency$_{B1}$	29%	77%	35%	53%	33%
B1 sluiceway effectiveness$_{B1}$ [b]			18.6	14.6	8.8
B2CC efficiency$_{B2}$				37%	30%
B2CC effectiveness$_{B2}$				7.0	5.9
B2CC efficiency				22%	17%
B2CC effectiveness				8.4	7.0
Steelhead					
Spillway efficiency	33%	c	55%	26%	39%
Spillway effectiveness	1.0	c	1.2	0.7	1.0
Fish-guidance efficiency$_{B1}$	59%	c	75%	a	a
Fish-guidance efficiency$_{B2}$	55%	c	59%	40%	40%
Fish passage efficiency	78%	c	84%	86%	83%
Fish-passage efficiency$_{B1}$	77%	c	91%	58%	30%
Fish-passage efficiency$_{B2}$	55%	c	59%	84%	79%
B1 sluiceway efficiency$_{B1}$	44%	c	65%	55%	29%
B1 sluiceway effectiveness$_{B1}$ [b]			34.1	15.1	7.5
B2CC efficiency$_{B2}$				74%	66%
B2CC effectiveness$_{B2}$				14.2	13.2
B2CC efficiency				49%	35%
B2CC effectiveness				19.1	14.7

[a] In 2004 and 2005, FGE$_{B1}$ could not be estimated due to the absence of guidance screens.
[b] Sluiceway discharge data were not provided in 2000 and 2001 so sluiceway effectiveness could not be calculated.
[c] Steelhead were not evaluated in 2001

Table 3.5. Passage Performance Metrics for Subyearling Chinook Salmon at Bonneville Dam during Summer Study Periods of 2000, 2001, 2002, 2004, and 2005 based on Radio Telemetry. Adapted from a table by Adams et al. (2006).

Metric	2000	2001	2002	2004	2005
Dates Sampled	6/20-7/24	7/1-7/24	6/21-7/25	6/21-8/4	6/15-7/25
Spillway Percent of Project Flow	54%	2.4%	43%	44.5%	53%
Spillway efficiency	65%	2%	58%	35%	51%
Spillway effectiveness	1.2	0.8	1.3	0.9	1.0
Fish-guidance efficiency$_{B1}$	29%	57%	43%	a	a
Fish-guidance efficiency$_{B2}$	25%	35%	47%	22%	24%
Fish passage efficiency	91%	40%	82%	68%	78%
Fish-passage efficiency$_{B1}$	77%	89%	72%	52%	70%
Fish-passage efficiency$_{B2}$	25%	35%	47%	50%	55%
B1 sluiceway efficiency$_{B1}$	29%	77%	35%	53%	59%
B1 sluiceway effectiveness$_{B1}$ [b]			18.6	14.5	2.8
B2CC efficiency$_{B2}$				37%	40%
B2CC effectiveness$_{B2}$				7.0	5.9
B2CC efficiency				22%	19%
B2CC effectiveness				5.9	6.4

[a] In 2004 and 2005 , FGE$_{B1}$ could not be estimated due to the absence of guidance screens.
[b] In 2000 and 2001, sluiceway effectiveness could not be estimated due to the absence of sluiceway discharge data.

3.2.1 Effect of Spill on Spillway Efficiency

Percent spill is the primary factor affecting spill efficiency. This variable explains most of the variation among years, seasons, species, and even spill treatments. On the other hand, spill effectiveness at Bonneville Dam is near 1:1 and mostly independent of percent spill. If we plot all 24 estimates of spill efficiency versus percent spill in Tables 3.2 through 3.5, percent spill explains 85% of the variation in spill efficiency (Figure 3.2), regardless of sampling method, year, season, or species. Accordingly, the lowest estimates came from the studies during the drought of 2001 and estimates from the wettest study (2002) produced among the highest estimates. This plot is similar to many that have been presented on daily or hourly time scales in the hydroacoustic studies, but is unique in that it integrates estimates from all studies (hydroacoustic and radio-telemetry). Seasonal estimates have the advantage of being more precise than daily or hourly estimates, and they are available for both methods, whereas radio telemetry cannot provide robust daily or hourly estimates because of sample size limitations. However, seasonal estimates do not capture the full range in percent spill at Bonneville Dam because strong diel and treatment variations are averaged out. Therefore, it is advantageous to examine results of some spill-treatment studies and plots of day and night estimates from hydroacoustic studies.

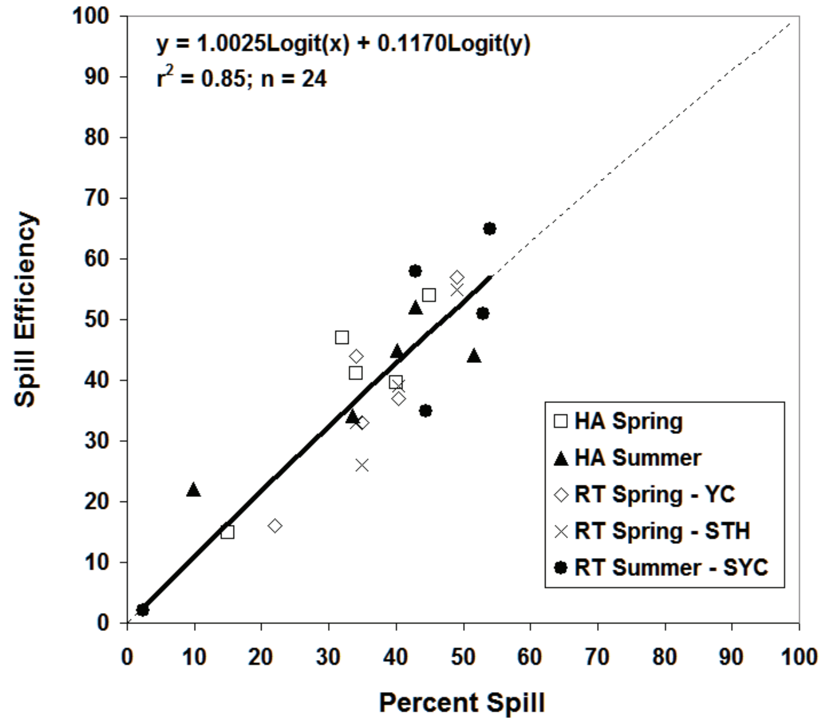

Figure 3.2. Plot of Spill Efficiency Estimates on Percent Spill based on Data in Tables 3.2-3.5. Abbreviations include HA = hydroacoustics, RT = radio telemetry, YC = yearling Chinook salmon, STH = steelhead, and SYC = subyearling Chinook salmon.

In 2002, two spill treatments were defined for their effects on spill efficiency:

1) The Day Cap Treatment was a typical diel spill treatment of about 57,000 cfs during the day and spill to the gas cap at night. Mean discharge was about 80,000 cfs in spring and 81,000 cfs in summer. The range was from 57,000 cfs during the day to 210,000 cfs at night in spring and from 57,000 cfs during the day to 171,000 cfs at night in summer.

2) The Total Dissolved Gas Cap Treatment was day and night spill to the TDG limit and averaged 128,000 cfs in spring and 118,000 cfs in summer. The range was about 75,300 cfs to 210,000 cfs in spring and from about 63,000 cfs to 171,000 cfs in summer.

For spring, estimates of spill efficiency for the two treatments are reasonably close to what would be predicted from the regression equation in Figure 3.2, given average estimates of percent spill (Table 3.6). In summer, the regression line in Figure 3.2 would forecast estimates that would be close to the hydroacoustic estimates but lower than radio-telemetry estimates. Evans et al. (2006b) found no significant difference in spill efficiency between the two treatments for subyearling Chinook salmon, although they did find differences between high spill during the day or night and low spill during the daytime part of the Day Cap treatment. Spill to the gas cap at night occurred in both defined treatments, and this may be partially responsible for confounding the results because the predominant arrival time of fish at the Project on a given treatment day could be the determining factor affecting spill efficiency. For example, if most fish arrived and passed at night during the high spill part of the Day Cap treatment, then spill efficiency would be inflated for that treatment.

Table 3.6. Spring and Summer 2002 Spill Efficiency Estimates

Spill Treatment	Hydroacoustic Estimate[a]	Radio Telemetry Estimates[b]	
		Yearling Chinook	Steelhead
Spring			
Overall	54%	56%	55%
Day Cap (mean = 80,000 cfs; 36%)	44%	46%	37%
TDG (mean = 128,000 cfs; 55%)	64%	64%	65%
Summer		**Subyearling Chinook**	
Overall	45%	58%	
Day Cap (mean = 81,000 cfs; 32%)	38%	55%	
TDG = 118,000 cfs 47%; 47%)	52%	59%	

[a] Recalculated from data in Ploskey et al. 2006b
[b] Evans et al. 2006a and 2006b

Ploskey et al. (2006b) reanalyzed all previous project-wide hydroacoustic data after percent spill estimates for 2000-2004 were corrected because of an error in the rating curve. They found a highly significant relationship between day and night estimates of spill efficiency and percent spill (Figure 3.3). A lot of the scatter in Figure 3.3 resulted from among-year differences in estimates, and regressions from three of the five years day and night estimates of percent spill explained over 75% of the variation in spill efficiency (Figure 3.4). Regressions for three of the five years 4had significantly higher r^2 values than did the pooled regression in Figure 3.3. Similar types of plots have been made using hourly data (e.g., Ploskey et al. 2003; Ploskey et al. 2005) but there is a greater risk of autocorrelation in those estimates than there is in using day and night estimates.

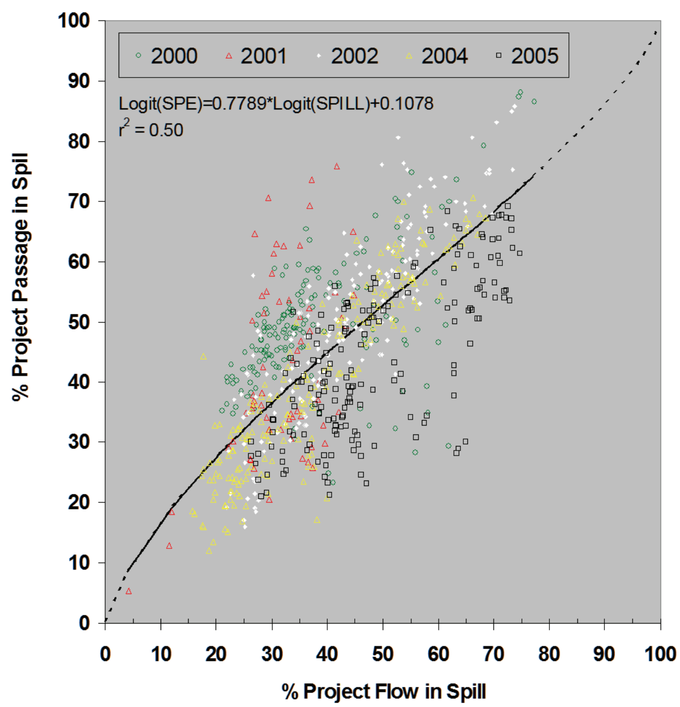

Figure 3.3. Regression of Day and Night Estimates of Spillway Efficiency on Percent Spill

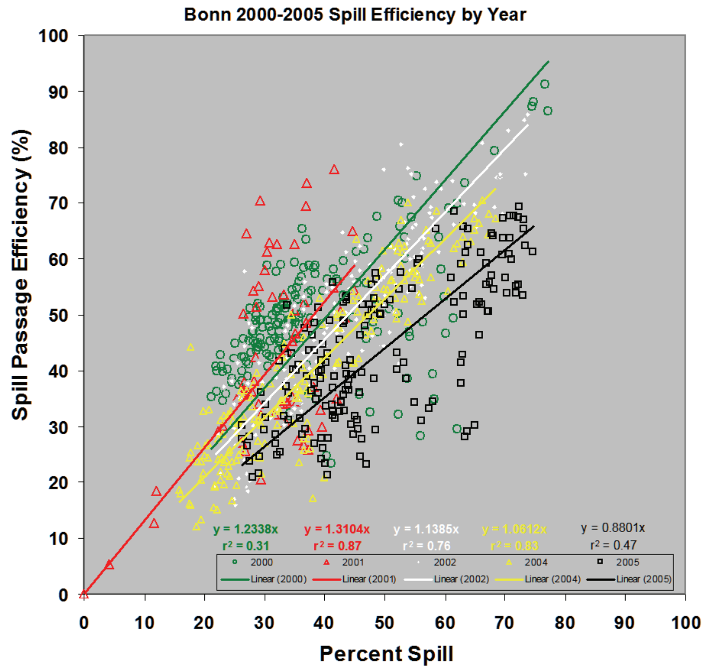

Figure 3.4. Regression of Spill Efficiency on Percent Spill by Study Year at Bonneville Dam. Points are from five different years and were estimated for day and night period of each day sampled.

3.2.2 Effect of Spill on Spillway Effectiveness

Another composite plot based on estimates from hydroacoustics and radio-telemetry shows that spill effectiveness is mostly independent of percent spill and is near 1:1 over most of the range in percent spill (Figure 3.5), as expected given the 1:1 slope of the regression in Figure 3.2. The plot of all data points is similar to trends observed in the reanalysis of day and night estimates from hydroacoustic studies (Figure 3.6). At best, there is a weak negative relationship between spill effectiveness and percent spill. The variation in point estimates tends to decrease and estimates converge with increasing percent spill.

The weak negative relationship between spill effectiveness and percent spill at Bonneville Dam probably results from the isolation of the spillway from powerhouses. Spill effectiveness at Columbia River dams typically is higher than the average at Bonneville Dam. For example, spill effectiveness at Lower Granite Dam in spring 2002 ranged from 1.8 to 3.3 and averaged 2.2 (Anglea et al. 2003). Overall spill-passage effectiveness at John Day Dam was 2.7 in spring and 2.3 in the summer of 2002 (Moursund et al. 2003). In both examples, project operations and the proximity of the project powerhouse to the spillway contributed to the spillway being able to take fish away from the powerhouse and concentrate them in spillway passage. For effectiveness to be much above 1:1 at Bonneville Dam, fish would have to preferentially select the spillway over either powerhouse. Unfortunately, islands funnel fish to the three forebays before fish are exposed to forebay conditions that might allow them to make a selection (see Chapter 2). Telemetry estimates of spill effectiveness generally were slightly lower than hydroacoustic estimates for Bonneville Dam, and those results also support the hypothesis that spillway isolation from both powerhouses prevents the spillway from attracting fish from either powerhouse forebay. This point is consistent with the data on movement between areas (B1, spillway, B2) presented near the end of Chapter 2.

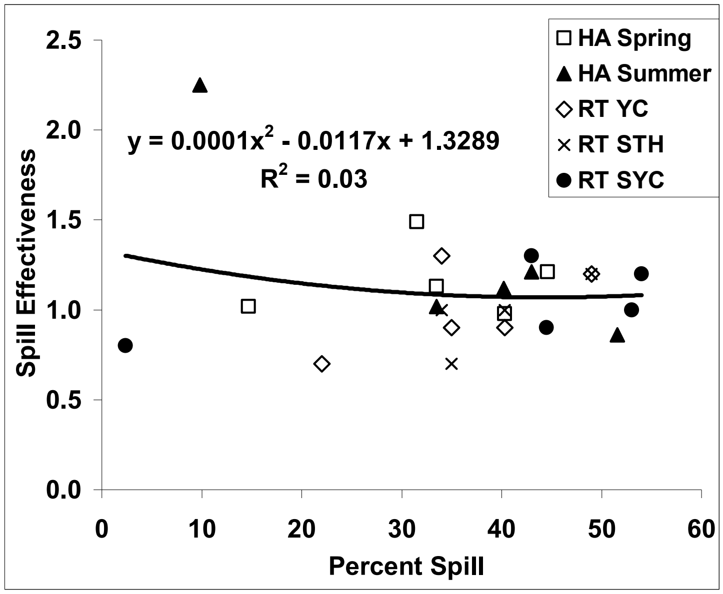

Figure 3.5. Plot of Spill Effectiveness Estimates on Percent Spill based on Data in Tables 3.2-3.5. Abbreviations include HA = hydroacoustics, RT = radio telemetry, YC = yearling Chinook salmon, STH = steelhead, and SYC = subyearling Chinook salmon.

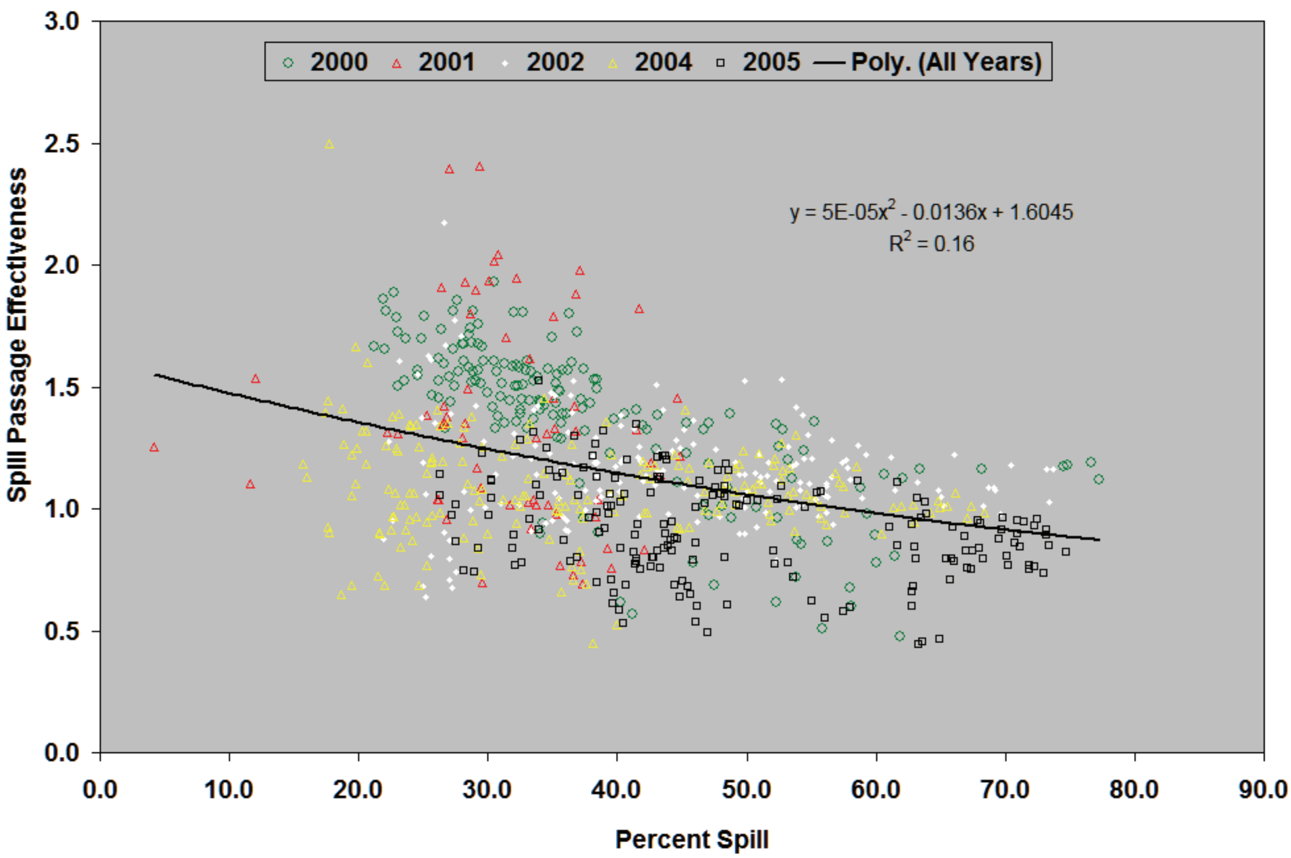

Figure 3.6. Plot of Day and Night Spill Effectiveness Estimates on Percent Spill (from Ploskey et al. 2006b)

Radio telemetry data also indicate that few fish detected in one of the three forebays move to a different forebay before passing the project. Lateral smolt distribution on approach to Bonneville Dam influenced whether the ultimate passage route was B1, the spillway, or B2 (e.g., Hensleigh et al. 1999). In 1996, 1997, and 1998, investigators coupled data describing the location of radio-tagged smolts upstream of Boat Rock with data identifying the location where these tagged fish passed the dam (Holmberg et al. 1996, Hensleigh et al. 1999, Hansel et al. 1999). Fish distributed to the south side of the channel were likely to pass the dam at B1 or the spillway. Fish distributed to the north side of the channel were likely to pass the dam at B2 or the spillway.

3.2.3 Effect of Percent Spill B1 and B2 Passage

Increasing spill to increase fish passage takes flow and fish from B1 and B2, both of which include non-turbine, surface-flow routes. The magnitude of effect when the respective powerhouses are impacted depends upon the assigned generation priority. For example, in 2005 when B2 was the priority powerhouse for generation, the percentage of fish and flow passing the Project through B1 declined precipitously as the percent spill increased from 25% to 40% (Figure 3.7). Although spills above 40% had little effect on fish passing B1 because it had nearly bottomed out, there was a significant decrease in fish passing B2 (Figure 3.8).

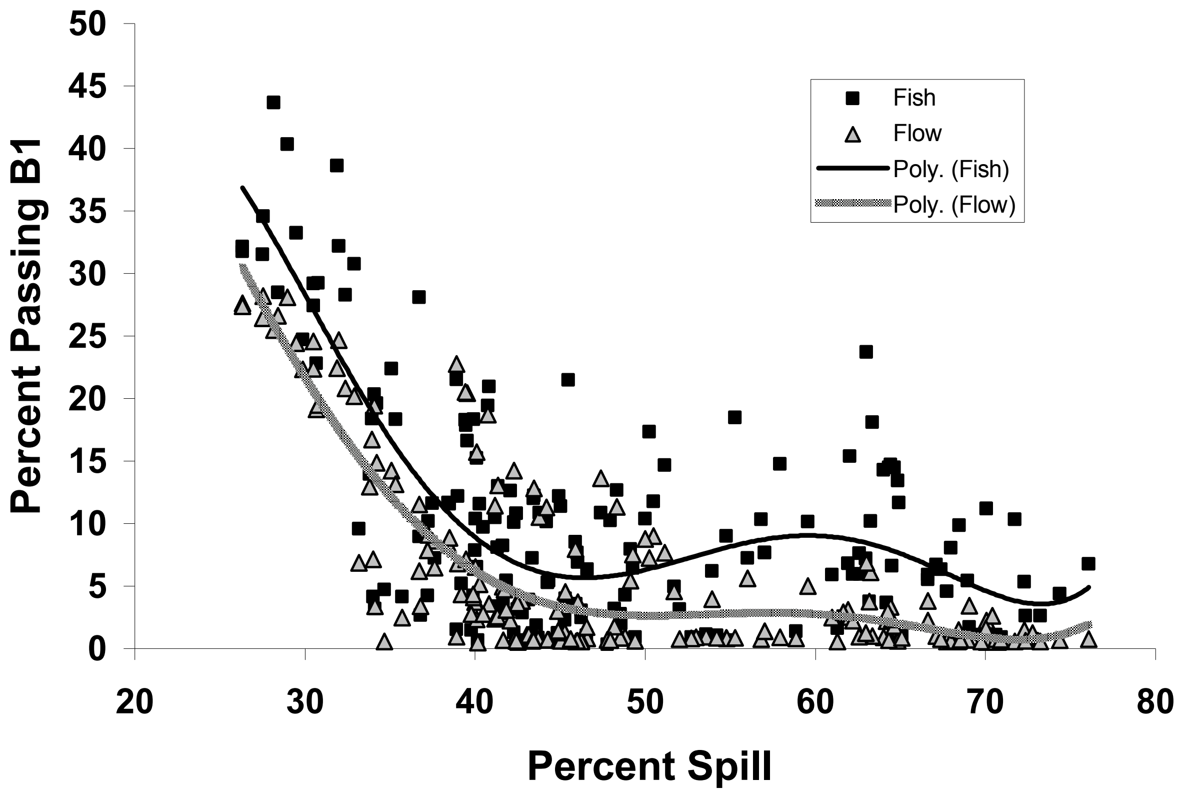

Figure 3.7. Trends in the Percent Fish and Flow Passing B1 as a Function of Percent Spill. Points include all day and night estimates from both passage seasons (from Ploskey et al. 2006c).

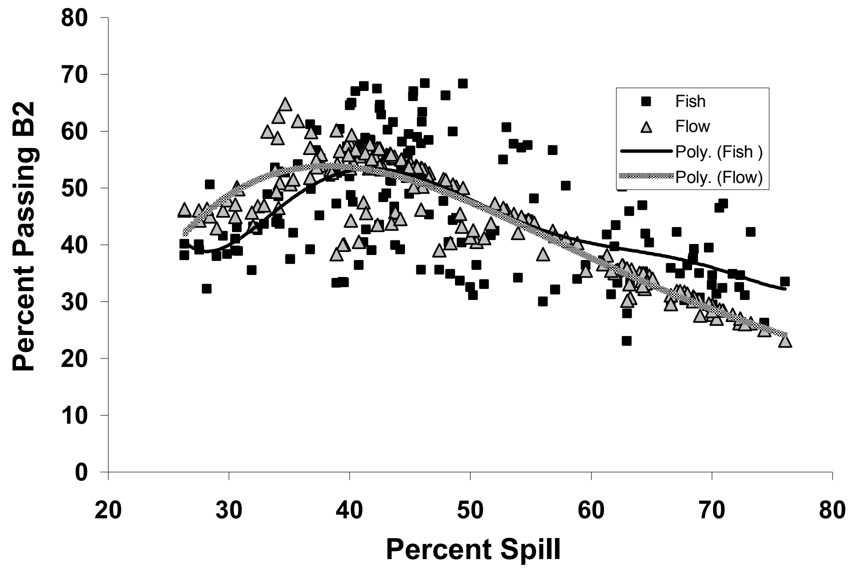

Figure 3.8. Trends in the Percent of Fish and Flow Passing B2 as a Function of Percent Spill. Points include all day and night estimates from both passage seasons in 2005. From Ploskey et al. (2006c).

3.2.4 Effect of Percent Flow on Surface Flow Outlet Efficiency

Based upon all available seasonal estimates from hydroacoustic and radio telemetry studies (Tables 3.2 through 3.5), the efficiency of the B1 sluiceway relative to B1 was correlated with the percent of B1 flow to that route (Figure 3.9). Within-season day and night estimates show the full range of effect much more clearly (Figure 3.10). B1 sluiceway efficiency increased very rapidly at low levels of percent flow. On average, the percent of B1 passage through the B1sluiceway was about 40% at 1% of B1 flow (the minimum flow), 73% at 5% flow, 83% at 10% flow, and 88% at 15% flow.

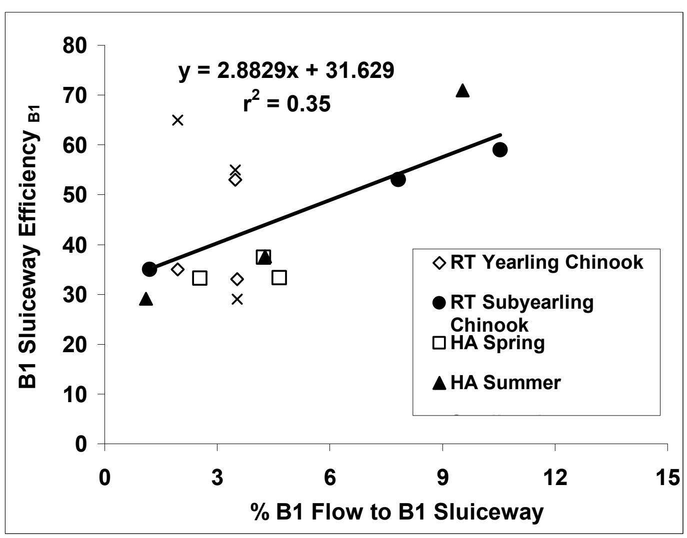

Figure 3.9. Regression of Seasonal Estimates of B1 Sluiceway Efficiency Relative to B1 on Percent of B1 Flow into the Sluiceway

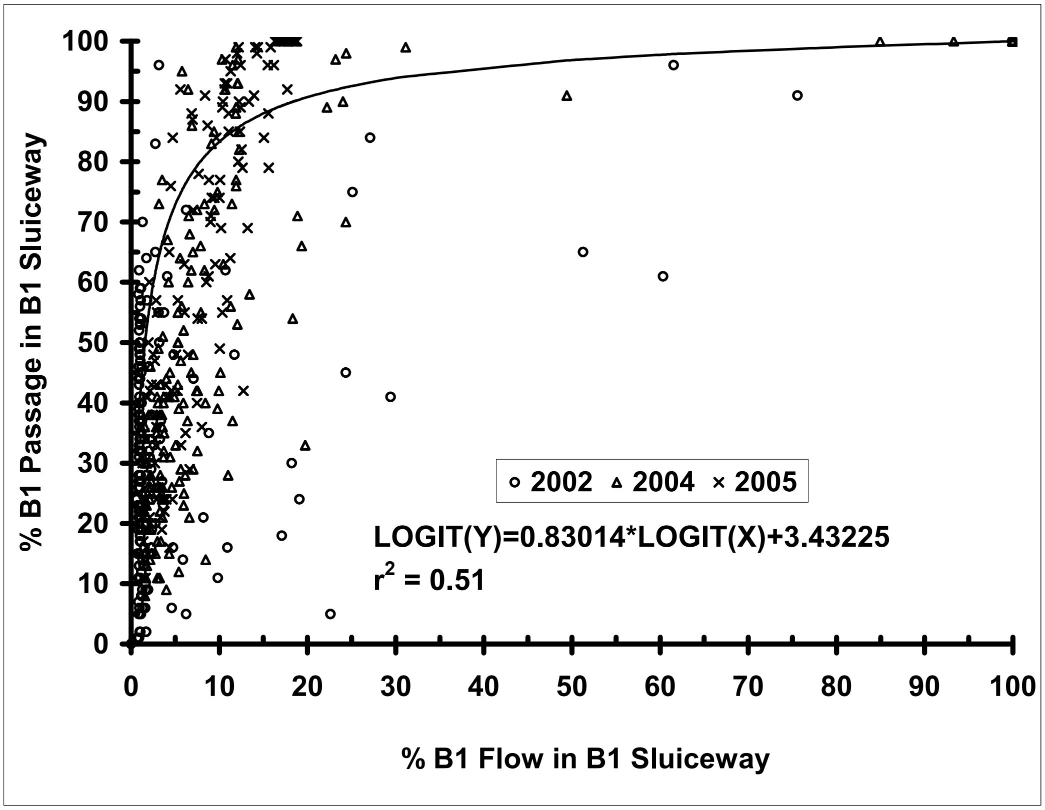

Figure 3.10. Logit Regression of Day and Night Estimates of B1 Sluiceway Passage Efficiency on Percent of B1 Flow Passing the B1 Sluiceway (from Ploskey et al. 2006b)

Examination of the B2CC efficiency estimates in Tables 3.4 and 3.5 clearly indicate that steelhead are much more likely than juvenile Chinook salmon to pass into the B2CC outlet and that hydroacoustic estimates are closer to estimates for juvenile Chinook salmon. The average B2CC efficiency relative to B2 was 70% for steelhead, compared with just 34% for yearling Chinook salmon and 39% for subyearling Chinook salmon. Hydroacoustic estimates averaged 32% in spring and 42% in summer, both of which are similar to respective estimates for Chinook salmon yearlings in spring and subyearlings in summer. This tendency of higher steelhead efficiency was only apparent in one year of B1 sluiceway data, perhaps because B1 outlets have low discharge compared with the B2CC.

There were too few seasonal estimates of B2CC efficiency for regression on percent of B2 flow to the B2CC, but daily hydroacoustic data from 2004 and 2005 show a trend similar to that observed for the B1 sluiceway (Figure 3.11). The percent of B2 passage through the B2CC was 30% at 4% of B2 flow (the minimum flow), 36% at 5% flow, 52% at 10% flow, and 62% at 15% flow (Figure 3.11). The remaining percentages of B1 or B2 passage at any percent flow represent what would pass through adjacent turbines.

At just 6% of project flow, predicted passage of all surface-flow outlets was over 30% of project passage (Figure 3.12), and this was at least three times higher than percent passage predicted for spill at that level (Figure 3.13). Percent of project flow through all surface-flow outlets explained 44% of the variation in project fish passage there (Figure 3.12).

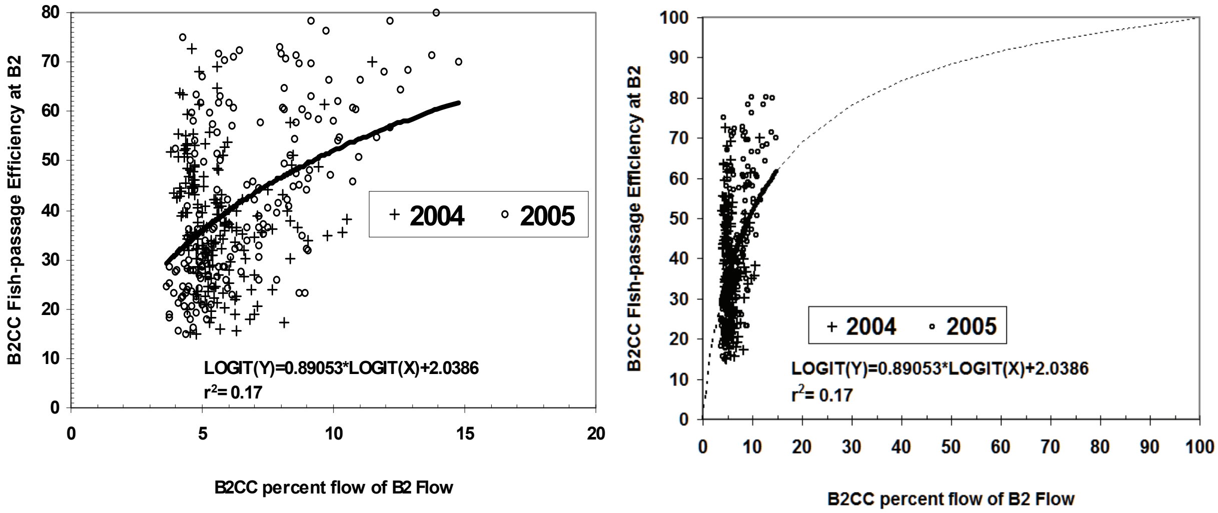

Figure 3.11. Logit Regression of Day and Night Estimates of the B2CC Passage Efficiency on Percent of B2 Flow Passing into the B2CC. The right plot shows full extrapolation to known endpoints as a dashed Line. From Ploskey et al. (2006b).

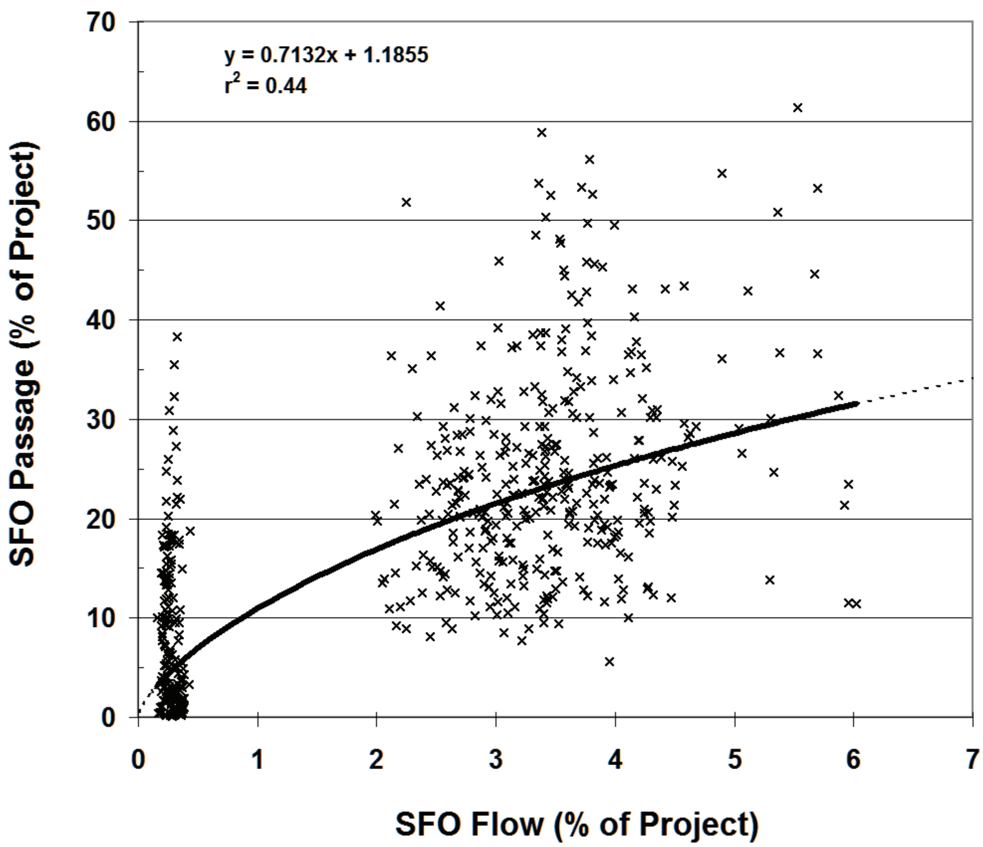

Figure 3.12. Logit Regression of Day and Night Estimates of Percent of Project Fish Passage through Surface Flow Outlets (SFO = B1 Sluiceway and B2CC Combined) on Percent of Project Flow through the Same Routes. The dashed portion of the line is an extrapolation toward known endpoints (0,0 and 100,100). From Ploskey et al. 2006b.

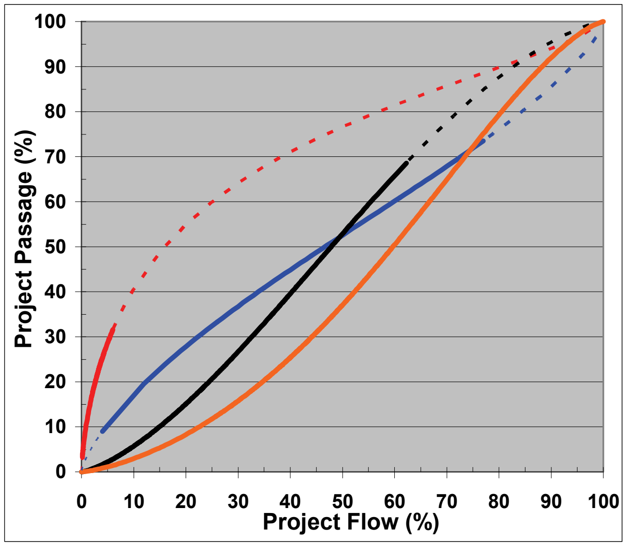

Figure 3.13. Logit Regression Lines Summarizing Percent of Project Passage by Route as a Function of Percent of Project Flow through the Same Route. The red line is the predicted response for surface flow outlets, blue is for spill, black is for B1 turbines, and orange is for B2 turbines. Lightly dashed portions of lines are extrapolations to known endpoints. From Ploskey et al. (2006b).

3.2.5 Effect of Percent Flow on Surface Flow Outlet Effectiveness

The effectiveness of the B1 sluiceway had a highly significant negative correlation with the percent of B1 flow passing that route (Figure 3.14) based upon all seasonal hydroacoustic and radio telemetry estimates in Tables 3.2 through 3.5. This trend is similar to that observed by Ploskey et al. (2006b) based upon day and night estimates from hydroacoustic studies (Figure 3.15), although the daily estimates afford a look at responses over a much wider range of percent flow than do the seasonal estimates.

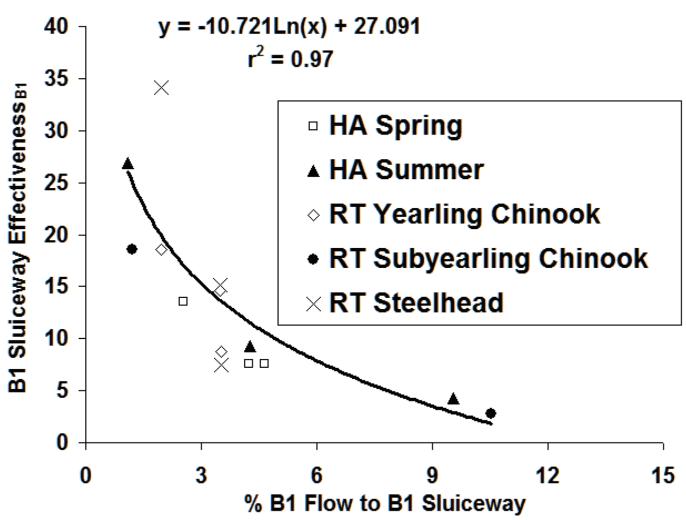

Figure 3.14. B1 Sluiceway Effectiveness as a Function of the Percent of B1 Flow into the B1 Sluiceway. Seasonal estimates are from Tables 3.2 through 3.5.

Percent of B1 flow into the B1 sluiceway explained 67% of the variation in B1 sluiceway effectiveness, mostly because the effectiveness of the B1 sluiceway was very high at low flow percentages and then declined exponentially, something that was not observed for the spillway (Figure 3.15). Differences between predicted estimates of effectiveness for the B1 sluiceway and the spillway based upon percent flow through the respective routes were much larger at low percent flow (20:1 at 1% flow) than they were at high percent flow (2:1 at 80% flow).

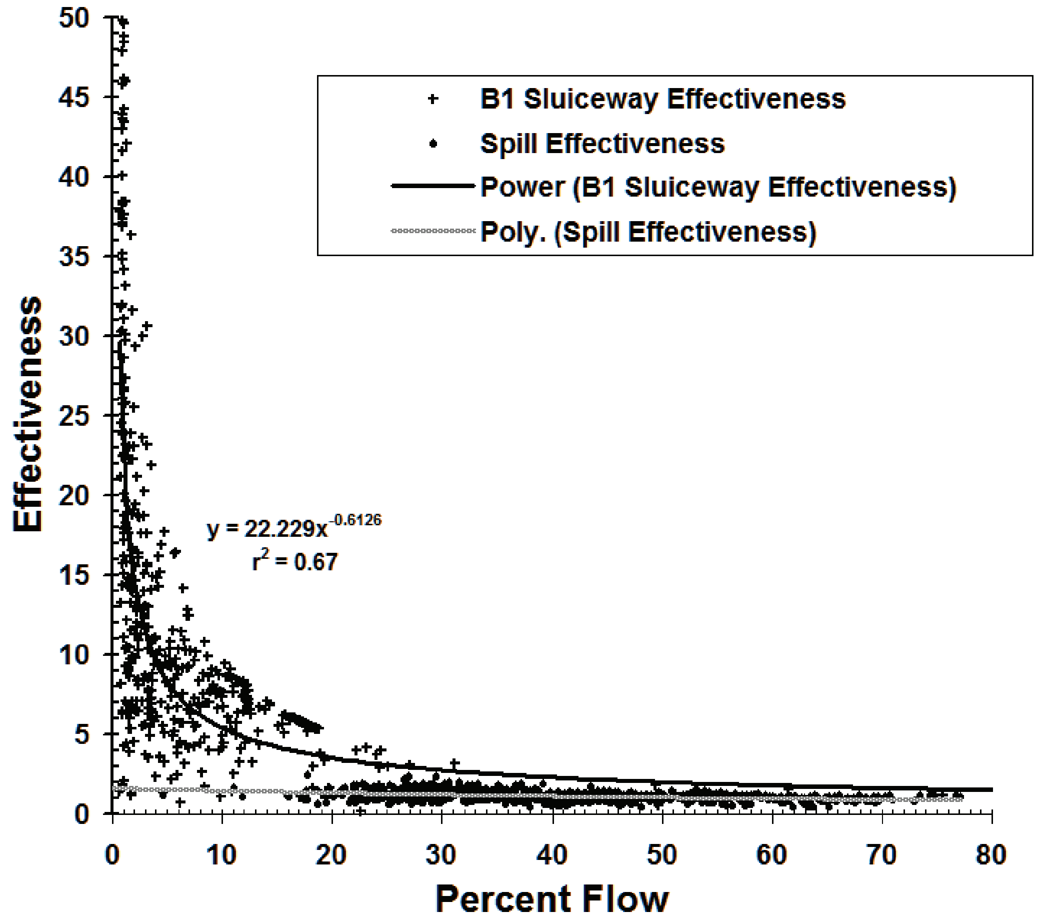

Figure 3.15. Regression of Day and Night Estimates of B1 Sluiceway Effectiveness on Percent of B1 Flow. The trend for spill effectiveness is shown for reference. From Ploskey et al. 2006b.

Based upon seasonal estimates of effectiveness relative to B2 (Tables 3.2-3.5), the B2CC was much more effective for steelhead (13.2-14.2) than it was for yearling or sub-yearling Chinook salmon (5.9-7.0) or for the run at large (5.8-7.7). In fact, radio telemetry data indicate that the B2CC passed 35% (2004) and 49% (2005) of the steelhead at the entire Project in just 4% of the flow.

There were insufficient seasonal estimates to plot B2CC effectiveness as a function of the percent of B2 flow into the collector, so we relied on day and night estimates from hydroacoustic studies (Figure 3.16). A similar trend of high effectiveness at low flow percentage was observed for the B2CC, where predicted effectiveness was about 8:1 at 4% of B2 flow through the B2CC and about 4:1 at 15% flow (Figure 3.16). The range of percent flow for the B2CC (4-15% of B2 flow) was much narrower than it was for the B1 sluiceway (1%-100% of B1 flow) and the spillway (4%-80% of project flow), and this probably explains the low r^2 of 14% for the B2CC data. At 4% flow, the normal operating percentage for the B2CC, effectiveness was about 5.33 times higher than spill effectiveness (Figure 3.16).

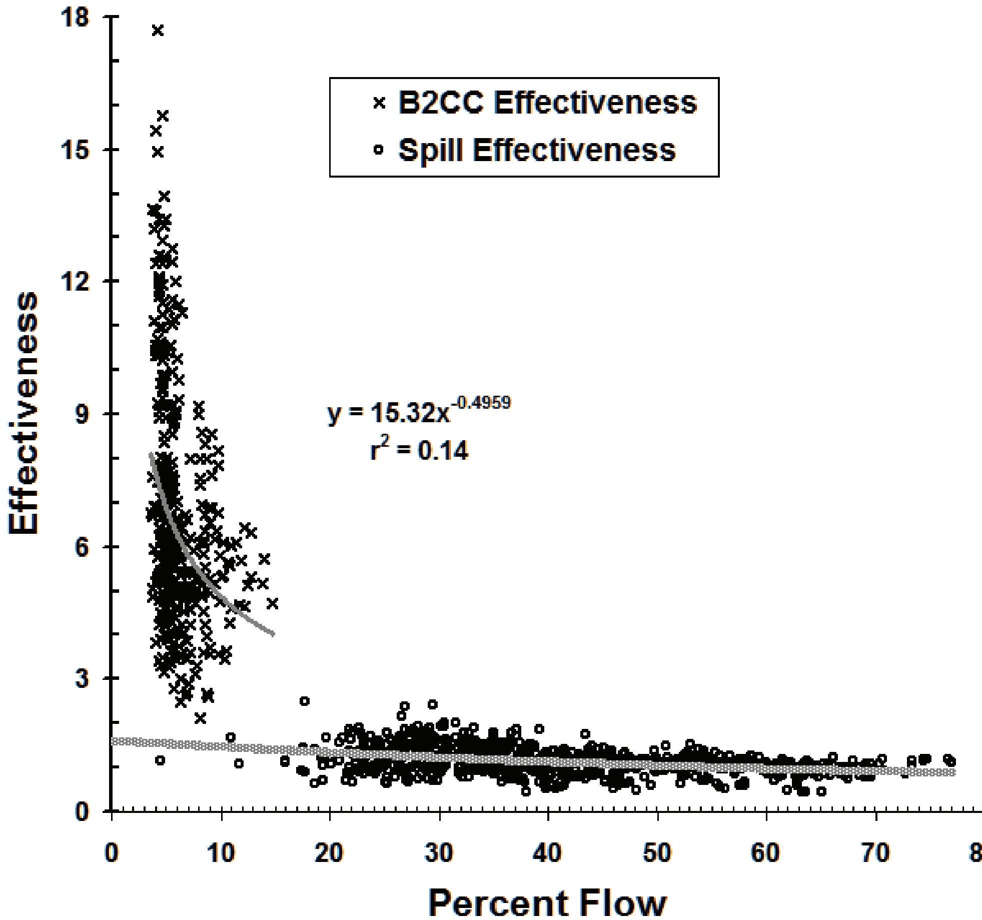

Figure 3.16. Regression of Day and Night Estimates of B2CC Effectiveness on Percent of B2 Flow. The trend for spill effectiveness as a function of percent spill also is shown for reference. From Ploskey et al. 2006b.

3.2.6 Effects of Spill on Project Fish-Passage Efficiency

When the management goal is to maximize fish passage through non-turbine routes, the combined effect of management is reflected in both the project-wide and powerhouse FPE. Estimated project FPE has varied substantially during the five years of project study. In a typical water year the goal of maximizing project FPE has substantially guided project operations. High spill discharge rates are considered necessary to compensate for low fish guidance rates at both powerhouses, especially in summer. The spill level and percent of total discharge spilled are restricted by water availability and power demand and by the legally set downstream total dissolved gas (TDG) cap of 120% of saturation that is meant to limit gas-related damage and mortality downstream. In a typical year, spill is set to between 50 and 75 kcfs during the day and 100 to 140 kcfs at night. Night spill can be higher because upstream migrating adult salmonids are not thought to move much at night and are unlikely to be swept back down through the spillway, whereas smolts move through deeper passage (under spill gates or through turbines) at night than during daytime (Thorne and Johnson 1993).

A plot of all seasonal FPE estimates in Tables 3.2 through 3.5, without regard to sampling method, season, or species, provided a scatter plot and regression that explained 71% of the variation in FPE (Figure 3.17). This plot had a similar intercept but steeper slope than one based upon day and night estimates of FPE from hydroacoustic studies (Figure 3.18). According to Figure 3.17, each 1% increase in percent spill buys a 0.7% increase in FPE. However, a known endpoint for Figure 3.17 is 100% FPE at 100% spill, which indicates that the true relationship must be curvilinear. There was a lot of variation in slopes and intercepts of regression lines among the five years (Figure 3.19). Regression lines varied a lot among years, with percent spill explaining from 47% to 79% of the day and night variation in fish-passage efficiency (Figure 3.19). Slopes in 2000 and 2002 (0.29 and 0.38) were less than slopes in 2001, 2004, and 2005. Intercepts also varied widely, from lows in 2004 (37%) and 2005 (28%) to highs in 2000 (69%) and 2002 (62%). However, data acquired during days of low spill and no spill in 2001 were most important for defining the intercept, which was about 49% when there was no spill. There were no data collected when spill was < 15% in other years so the intercepts are backward extrapolations beyond available data.

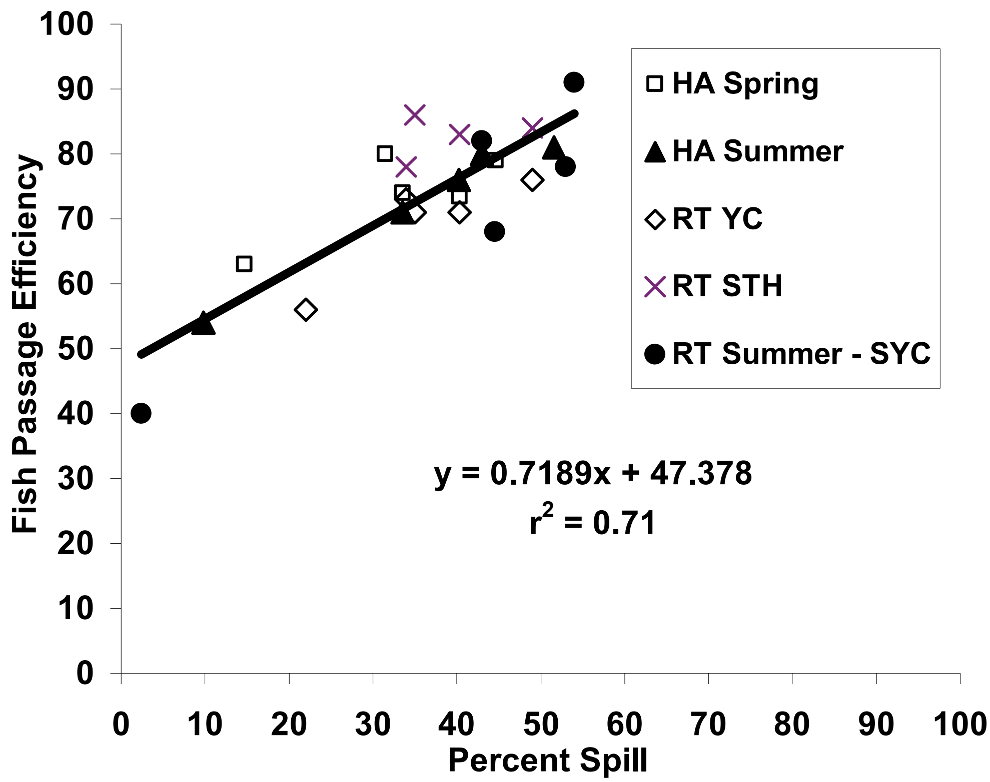

Figure 3.17. Regression of Seasonal Estimates of Fish-Passage Efficiency on Percent Spill. Data are from Tables 3.2 through 3.5.

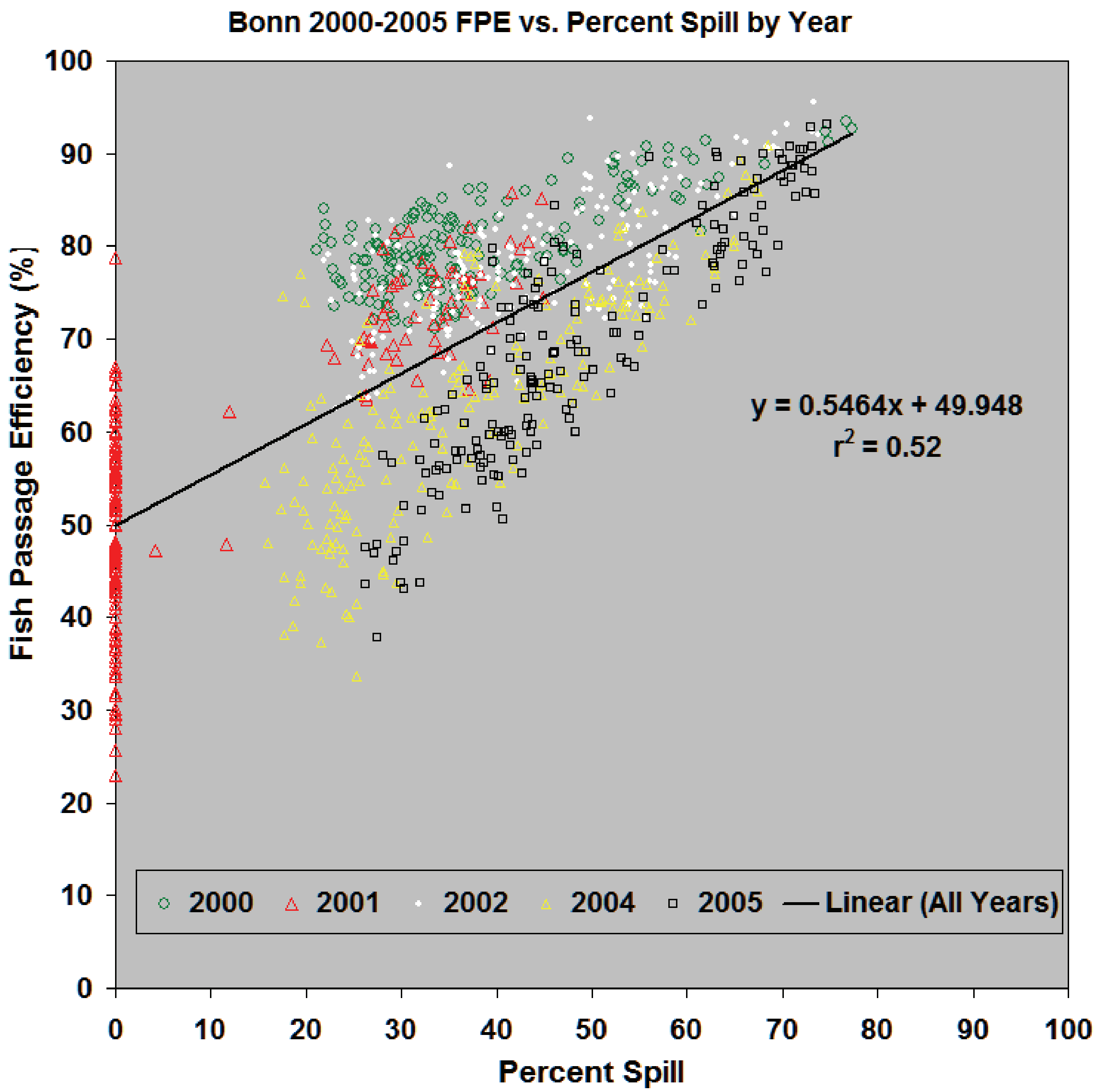

Figure 3.18. Regression of Fish-Passage Efficiency on Percent Spill for Bonneville Dam. Points are from five different years and were estimated for day and night periods. From Ploskey et al. (2006b).

Given relations between FPE and percent spill at Bonneville Dam (Figures 3.17 and 3.18), it was not surprising that spring FPE was higher during a TDG spill treatment than it was during a Day Cap treatment (Table 3.7). However, we were surprised that neither method showed expected increases in FPE in summer. In fact, Evans et al. (2006b) found a significant difference but with higher FPE for the Day Cap treatment. As Evans et al. (2006b) correctly pointed out, spill to the gas cap at night occurred in both treatments, and this may be partially responsible for confounding the results because the predominant arrival time of fish at the spillway on a given treatment day could be the determining factor affecting FPE. For example, if most fish arrived and passed at night during the high spill part of the Day Cap treatment, then FPE would be inflated for that treatment.

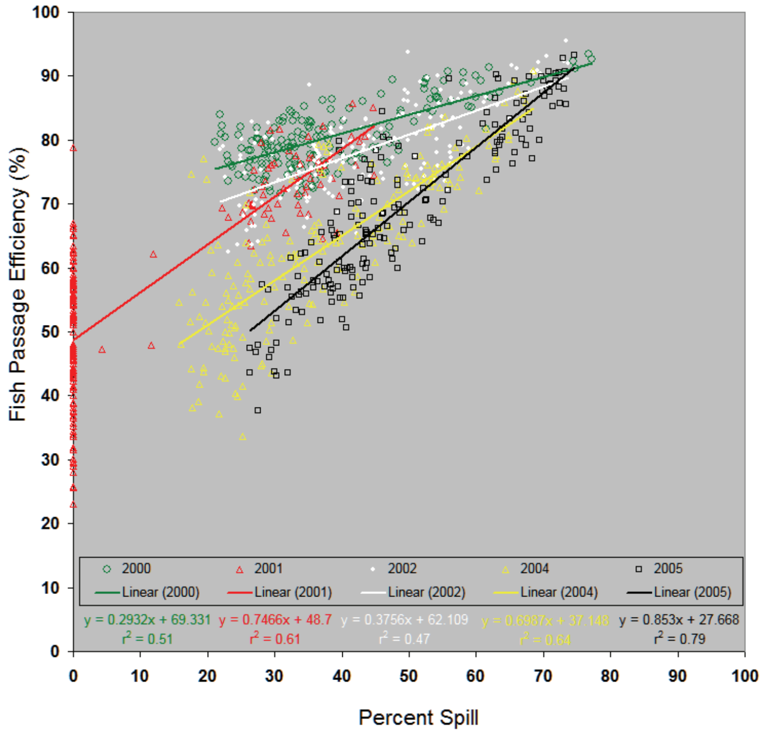

Figure 3.19. Regression of Fish-Passage Efficiency on Percent Spill by Year for Bonneville Dam. Points are from five different years and were estimated for day and night periods. From Ploskey et al. (2006b).

Table 3.7. Spring and Summer 2002 Fish Passage Efficiency Estimates

Spill Treatment	Hydroacoustic Estimate[a]	Radio Telemetry Estimates[b] Yearling Chinook	Steelhead
Spring			
Overall	79%	76%	84%
Day Cap (mean = 80,000 cfs; 36%)	75%	70%	76%
TDG (mean = 128,000 cfs; 55%)	84%	80%	88%
Summer		**Subyearling Chinook**	
Overall	76%	82%	
Day Cap (mean = 81,000 cfs; 32%)	73%	86%	
TDG = 118,000 cfs 47%; 47%)	74%	81%	

[a] Recalculated from data in Ploskey et al. 2006b
[b] Evans et al. 2006a and 2006b

Total Project FPE estimates of 74% in spring and 71% in summer 2004 were made possible primarily by surface passage routes (Ploskey et al. 2005). There were no traveling screens (STS) deployed at B1 in 2004, spill efficiency was below average, and B2 FGE was about average for non-drought years. Fish passage efficiency is functionally a result of differences in structure and operations. For instance, the B1 sluiceway and B2CC were responsible for a large proportion of the estimated total project fish passage relative to the amount of water discharged through those surface routes (Figure 3.20). Although the contribution of surface passage routes to FPE did not completely make up for the absence of screens at B1 or below-average spill efficiency, it did keep spring FPE within 6% of estimates in 2000 and 2002 and summer FPE within 9% of 2000 levels and 4% of 2002 levels, two non-drought years. Surface passage was especially important in maintaining a relatively high (71%) FPE estimate in late summer, when Project FPE often declines. Project FPE calculated with no surface-passage component was about 67% in spring and 60% in summer. In 2004, B2 screen guidance was about average for that structure (just under 50% in spring and just over 35% in summer) and Project spill efficiency was the lowest of the three non-drought years sampled.

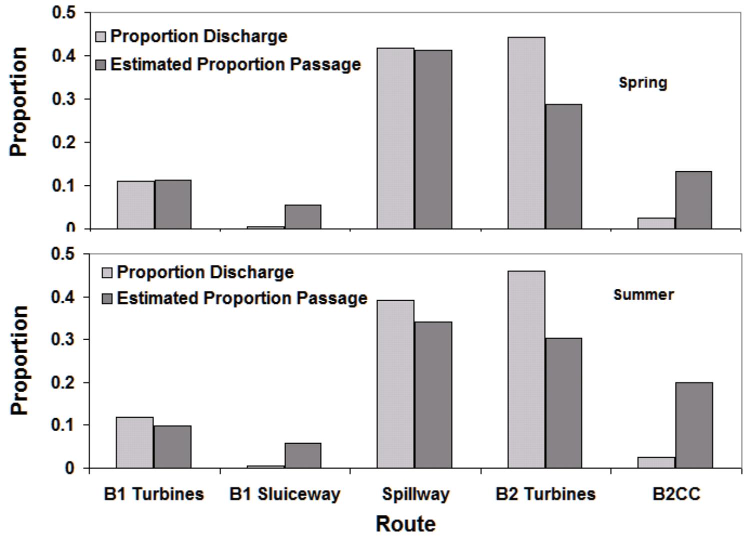

Figure 3.20. Distribution of Proportions of Total Project Discharge and Total Estimated Fish Passage through Different Structures at Bonneville Dam in Spring and Summer of 2004. (from Ploskey et al. 2005)

Adams et al. (2006) also noted that spillway efficiency was lower in 2004 and 2005 because more fish passed at B2, specifically through the corner collector. Although the addition of the corner collector did not increase Project FPE, it did achieve a Project FPE similar to that attained in previous years, mainly through spill. Furthermore, the corner collector helped achieve similar Project FPE with far less water than would have been used to attain the same FPE without the corner collector. The spillway discharged an average of 17 times more water than the corner collector.

An additional special study FPE evaluation of the early Spring Creek Releases of subyearling Chinook salmon was undertaken using three operational treatments in March 2004 (Ploskey et al. 2005). Bonneville Dam was operated according to the following three operational scenarios:

1. five days of 31,400 cfs spill with no B2CC operations
2. four days of B2CC operation with no spill
3. approximately seven days of no spill and no B2CC operation.

Spill was supposed to be 50,000 cfs but because of gauging errors it was actually only about 31,400 cfs and about 23% of project discharge during the spill treatments. Project power generation continued as usual during all three scenarios, with clear B2 priority, and all three B1 sluiceway entrances open. Results for project FPE, spill efficiency, and sluiceway efficiency during the three operational conditions are shown in Figure 3.21. Project FPE was about 54% during the spill and no B2CC operation, 45% during no spill-B2CC operation, and only 32% under the no-spill, no-B2CC condition. The radio telemetry estimate of FPE for summer 2001 was 40% under similar spill conditions because of a severe drought, although the B2CC was not functioning in 2001. The hydroacoustic estimate for summer 2001 was 54%. Passage of fish at the B1 sluiceway contributed from 1.7% to 5.1% to project FPE. Over three years of summer hydroacoustic estimates when subyearling Chinook salmon predominated, the B1 sluiceway passed an average of 7% of project passage. The B2CC accounted for about 17.1% of the Spring Creek hatchery fish that passed the Project and 24% of fish that passed at B2 during the no spill-B2CC operation.

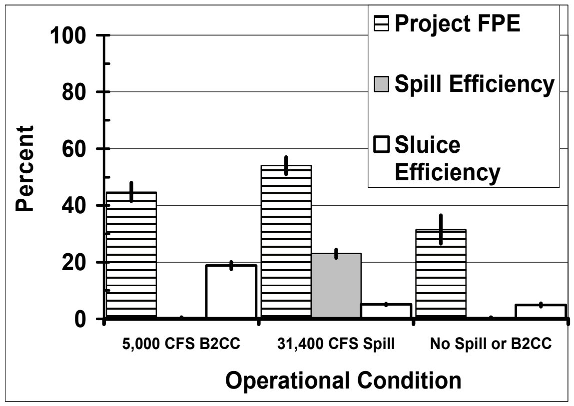

Figure 3.21. Project FPE, Spill Efficiency, and Sluiceway Efficiency (B1 + B2CC) during Three Operational Conditions Presented to Fish from the Spring Creek Hatchery Release in March 2004. Vertical bars are the 95% confidence limits on the estimates.

Running the B1 sluiceway and B2CC without spill produced a Project FPE that was nearly as high as that provided by 50,000 cfs of spill, B1 sluiceway operation, and no B2CC, and this was despite a poorly performing B1 sluiceway. Project FPE was as high during two of the days of B2CC-only operation as it was during the five days of spill. Under the other two days of B2CC only operation, Project FPE was only about 12% lower than average FPE under spill. In contrast, four of seven days of no spill and no B2CC produced an FPE that ranged from 16% to 39% lower than FPE during spill at this early point in the season.

3.2.7 Powerhouse FPE

Powerhouse-specific FPE estimates were made for the years 2000 through 2005 (except for 2003) using both hydroacoustics and radio telemetry methods, but estimates were only comparable for a few of the five years. When surface routes were functional and sampled and in-turbine screens were deployed, powerhouse FPE reflected the combined efficiency of surface-passage routes and screens. These combined efficiencies included hydroacoustic estimates of B1 FPE in 2002 only and of B2 FPE in 2004 and 2005 only, and radio-telemetry estimates of B1 FPE in 2000, 2001, and 2002 only and of B2 FPE in 2004 and 2005 only). From 2000 through 2002, B1 FPE averaged 74% for yearling Chinook salmon, 84% for steelhead, and 79% for subyearling Chinook salmon. In 2004 and 2005, B2 FPE averaged 56% for yearling Chinook salmon, 81.5% for steelhead, and 52.5% for subyearling Chinook salmon. The higher B2 FPE for steelhead was largely owing to the high B2CC efficiency. Hydroacoustic estimates of B2 FPE for 2004 and 2005 averaged 63% for both seasons. When no surface routes were sampled (B1 in 2001 by hydroacoustics) or functioning (B2CC was closed in 2000, 2001, and 2002), powerhouse FPE was the same as powerhouse FGE, which is described in Section 3.4 below. When screens were not deployed at B1 in 2004 and 2005, powerhouse B1 FPE was equivalent to B1 sluiceway efficiency relative to B1, which was described in Section 3.2.4 above.

3.2.8 Synthesis and Conclusion about Major Passage Metrics

Prioritizing routes by survival rate would seem to be a logical first step toward the goal of maximizing Project survival, and therefore a thorough understanding of route-specific survival is critical for choosing the best route for fish. After routes are ranked from highest to lowest survival, the next step would be to adjust project operations to maximize passage through the safest routes. If turbines were a safer route than some spill bays, then using spill to maximize FPE may not be consistent with the goal of maximizing Project survival. However, if the safest routes turned out to be non-turbine routes, and the goal was to maximize passage by non-turbine routes, then the discussion and recommendations of Ploskey et al. (2006b), which are paraphrased in the next paragraph, also make sense.

The most efficient approach to increase non-turbine passage is to optimize percent flow to the B1-sluiceway and B2CC because these routes can reduce turbine passage by out-competing adjacent turbines for fish. The spillway cannot compete directly with turbines for fish. Spill should not be eliminated, but it may be possible to reduce reliance on spill to pass juvenile salmonids by fully realizing all potential benefits of surface passage through structural and operational changes at the powerhouses. Turbines are about as efficient as the spillway at any percentage of project flow, but surface routes are much more efficient than turbines at low percent flow (Figure 3.13). The average percent of B1 flow through the B1 sluiceway (1%-2%) is well below an optimum amount of 10% (see Figure 3.10), but hopefully planned improvements in that system will greatly improve its performance in the future. Given the very high effectiveness of surface routes at the lowest flow (Figures 3.15 and 3.16), we recommend testing the use of many low-flow surface outlets at B1 versus the use of a few outlets passing equivalent flow. Responses of percent of adjacent powerhouse passage through surface flow outlets like the B1 sluiceway increased very rapidly at low levels of percent flow, and this clearly indicates that juvenile salmonids preferentially select surface outlets over adjacent turbines. The high effectiveness of surface outlets and proximity to turbines should make them the first choice of managers for optimizing flow to increase non-turbine passage rather than spill. Without structural modification, attaining 10% B1 flow to the sluiceway requires shutting down turbines, which is how 50%-100% of B1 flow to the sluiceway was possible at times. Given the B2 powerhouse priority, it is difficult to imagine increasing percent of B2 flow to the B2CC much above the median 4% observed in 2004 and 2005. The installation and testing of a smolt guidance device in the B2 forebay may be a viable alternative to increasing percent flow from 4% to 15%. Previous observations of 10%-15% of B2 flow to the B2CC always occurred at night when turbines were shut down to accommodate increased spill at night.

Percent spill clearly has an overriding influence on spill and fish-passage efficiency and is an important tool to improve spill and fish-passage efficiency, but spill effectiveness is nearly constant at just over 1:1 over a wide range of percent spill. Spill has been used to increase non-turbine passage at Bonneville Dam, but it is not an efficient use of water because the project has two islands that isolate spillway flow from powerhouse flow before fish can select a preferred route. Consequently, spill efficiency will always be directly proportional to percent spill, with effectiveness ranging from about 0.7 to 1.3.

3.3 Surface Flow Outlets

3.3.1 Introduction

Surface flow outlet (SFO) technology is a primary management strategy to safely pass juvenile salmonids at Bonneville Dam. An SFO is a non-turbine, water-efficient passage route with an overflow structure through which flow and fish pass over a dam. The Biological Opinions on operation of the Federal Columbia River Power System (FCRPS) (NOAA Fisheries 1995, 1998; 2000; 2004) mandated development of surface bypasses at Bonneville Dam, because FGE and smolt survival associated with turbine intake screens was substandard (e.g., Dawley et al. 1992; Gilbreath et al. 1993; Monk et al. 1999a). In the mid-1990s the USACE instituted a formal Surface Flow Bypass Program whose goal was to "develop and evaluate surface bypass and collection prototype concepts that will lead, if justified by prototype test results, to permanent systems for improving survival of juvenile salmon…" (USACE 1995). The Independent Scientific Advisory Board reviewed and supported this initiative (Bisson et al. 1999). Synthesis reports on SFO development at Bonneville Dam can be found in Giorgi and Stevenson (1995), Johnson et al. (1997), Dauble et al. (1999), and Johnson and Dauble (2006).

At Bonneville Dam, three surface flow outlets have been studied: the B1 Sluiceway, the B1 Prototype Surface Collector, and the B2 Corner Collector. Our purpose in this section is to describe physical, hydraulic, and biological characteristics of these three structures as juvenile salmonid passage routes.

3.3.2 B1 Sluiceway

For over 30 years, the Bonneville Dam First Powerhouse (B1) sluiceway has been operated as a non-turbine passage route for juvenile salmonids. An ice-trash sluiceway extends along the surface of the forebay side of the B1 powerhouse. There is a leaf gate above each turbine intake. Flow through sluice gates is strongly influenced by forebay elevation. Maximum total capacity of the sluiceway is about 2,100 cfs. A gate at the south end of the sluiceway controls sluiceway channel flow. At this point, flow plunges into a raceway, which turns downstream and discharges into the tailrace at the south end of the B1 powerhouse. The following material covers investigations of the B1 sluiceway as a passage route for downstream migrants, including the early studies of the 1960s-1980s, the 1996 trash-rack blockage study, and the total project passage studies in 1999-2005.

3.3.2.1 Early Studies: 1960s-1980s

Michimoto and Korn (1969) investigated the potential for passing smolts through the B1 sluiceway. Using mark-recapture techniques, they estimated that hundreds of thousands of smolts passed the dam via the sluiceway. These authors surmised that many more would have passed through the sluiceway had its flow been maximized at 1,500 cfs instead of the 832 cfs necessary for their sampling operations. Michimoto and Korn (1969) concluded that sluiceway passage was more similar to spillway passage than turbine passage because of the hydraulic and physical characteristics of each passage route. They recommended full-time B1 sluiceway operation at 1,500 cfs during the downstream migration period.

A decade later, Uremovich et al. (1980) found that juvenile salmonid passage in spring and summer at the sluiceway was significantly ($P < 0.01$) higher with "split" gates (4B, 6B, 7A, 10C) than with "adjacent" gates (6A, 6B, 6C). They observed the highest concentrations of fish in gatewells where the intakes are near or adjacent to walls (6B, 7A, and 10C). This suggested that forebay walls or shorelines, and possibly associated vortices or eddies, might serve to guide and concentrate smolts.

Willis and Uremovich (1981) continued sluiceway research at B1 in 1981. Their goal was to provide estimates of sluiceway efficiency under their proposed optimum operating conditions. Fisheries managers considered this information when they decided which smolt bypass alternative was preferred (STS, sluiceway, or both). Willis and Uremovich (1981) found that passage per sluice gate at 6B and 7A, respectively, was 6.1 and 3.7 times higher at full flow (~475 cfs per gate) than at half flow (~240 cfs per gate). This implied that "fish attraction" was positively related to the amount of water entering a sluice gate. They estimated sluiceway bypass efficiencies (sluice passage divided by total powerhouse passage) to be 83% for steelhead, 58% for yearling Chinook salmon, 50% for coho salmon, 42% for sockeye salmon, 10% for subyearling Chinook salmon "migrating naturally," and 4% for hatchery subyearling Chinook salmon. Given these results, Willis and Uremovich (1981) recommended the sluiceway at B1 be operated in conjunction with a STS bypass system. They felt a "hybrid" system would reduce delay and decrease turbine passage over either the STS or sluiceway as a stand-alone smolt bypass. A combination of sluiceway and STS has been operated routinely at B1 since the early 1980s.

Collectively, the early sluiceway research demonstrated that surface routes would pass appreciable numbers of smolts at B1. However, fisheries managers felt the sluiceway system was inadequate as a stand-alone system because sluiceway flow was limited to about 2,100 cfs, and conveyance and outfall conditions were poor. Therefore, an intake screen system was installed at B1.

3.3.2.2 Trash-Rack Blockage Study: 1996

In 1996 at B1, trashracks at units 3 and 5 were blocked to El. 33 ft (about 41 ft deep) as an inexpensive, preliminary surface bypass test. The purpose of the blockages was to occlude part of the intake entrance area to intensify and deepen the "zone of separation" between the turbine flow and surface sluiceway flow. The intent was to determine if surface-oriented smolts would exhibit an enhanced proclivity to resist sounding if a large zone of separation could be established.

The primary results of the evaluation of trash rack blockages at B1 in 1996 come from fixed hydroacoustics. Too few radio-tagged fish were present in the area of interest during the experimental treatments to provide meaningful radio telemetry estimates of passage. Blocking in spring increased sluiceway passage at Gate 3B by 14.6% and at Gate 5B by 12.8%; however, neither increase was statistically significant because the tests lacked sufficient statistical power (Ploskey et al. 1998). In summer 1996, blocking did not significantly increase sluice passage or sluice passage efficiency (Ploskey et al. 1998).

Split-beam transducers aimed upward about 10-15 ft upstream of Gates 3B and 5B were used to monitor the direction of fish movement. A ratio of upward-moving to downward-moving fish was used to characterize effects of the blockages. A ratio near 1 implies no effect, greater than 1 implies a positive effect, and less than 1 implies a negative effect. In front of Gate 3B, the ratio of upward-moving to downward-moving fish was significantly greater with the blockages in (mean ratio 4.0) than with them out (mean ratio 1.9). No significant difference in the upward/downward ratio was found at Gate 5B. In general, ratios of mean sluice passage rates with and without blockages were 4.8 for Gates 3B and 5B pooled, 6.8 for Gate 3B, and 2.2 for Gate 5B (Ploskey et al. 1998). The same ratio for turbine passage at

3B and 5B pooled was 0.56 (Ploskey et al. 1998). Daily passage was highly variable, which affected the ability to statistically detect differences in passage with and without blockages. In conclusion, the experiment with trash rack blockages at B1 in 1996 did not reveal negative impacts from the blockages.

3.3.2.3 Total Project Passage Studies: 1999-2005

Efficiency and effectiveness at the B1 Sluiceway, relative to the B1 powerhouse, were estimated as part of the total project passage studies designed to estimate fish passage efficiency for Bonneville Dam as a whole during 2000-2005. Recall, 2001 was a drought year, so the B1 turbines were operated sparingly during the downstream migration period. No passage studies were conducted in 2003. Except for 2000, B2 was the priority powerhouse for power production. Approximately one-third of the yearling and subyearling Chinook salmon passing B1 used the sluiceway during studies in 2000-2005; for steelhead, about one-half used the sluiceway and one-half used the B1 turbines (Tables 3.4 and 3.5). For the run-at-large during spring and summer, sluiceway efficiencies were also about one-third of total B1 passage (Tables 3.2 and 3.3). Seasonal effectiveness estimates for the B1 sluiceway average 9.6 in spring and 13.5 in summer for the run at large (Tables 3.2 and 3.3), 14 for yearling Chinook salmon, 18.9 for steelhead (Table 3.4), and 12 for subyearling Chinook salmon (Table 3.5).

3.3.2.4 Conclusion

The B1 sluiceway continues to be a valued passage route for juvenile salmonids at Bonneville Dam. It could provide the basis to develop a more extensive surface flow outlet at B1.

3.3.3 B1 Prototype Surface Collector: 1998-2000

3.3.3.1 Introduction

The USACE Surface Bypass Program started in 1995 with development of alternatives for SFOs at B1 (Harza and ENSR 1996a). The alternatives included a full powerhouse collection structure (called Alternative A), a high-flow corner collector at the south end of the powerhouse, and a bypass channel attached to intakes with extended bar screens. To test the SFO concept for Alternative A, a prototype surface collector (PSC, Figure 3.22) was retrofitted to the upstream face of B1 at units 3-6 in 1998.

The purpose of the PSC was to provide a field site to investigate hydraulic and biological performance for a potential surface bypass at B1. Fish entering the PSC passed through the structure into the turbine intake behind the PSC (Figure 3.23). The PSC was not designed to actually bypass fish around turbines. The intent was to use the PSC to examine entrance hydraulics and to examine the efficacy of surface bypass at B1 before building a large-scale prototype or full production surface bypass facilities at B1. An extensive biological evaluation was undertaken in 1998. In 1999, limited research occurred to prepare for culminating tests in 2000.

In 2000, the PSC was extended beyond units 3 through 6 to also cover units 1 and 2, because a noticeable number of smolts were observed in 1998 and 1999 to move obliquely from north to south across the forebay of the PSC. The PSC was thoroughly evaluated in 2000. The objectives for SFO research at B1 in 2000 were to 1) confirm proof-of-concept for the surface bypass at B1 that was established in 1998, 2) estimate PSC performance; and 3) study behavioral processes and mechanisms that affect performance to aid future surface bypass designs. The PSC results presented below will focus on the 2000 study because it was the most extensive and the PSC was at its highest level of structural development.

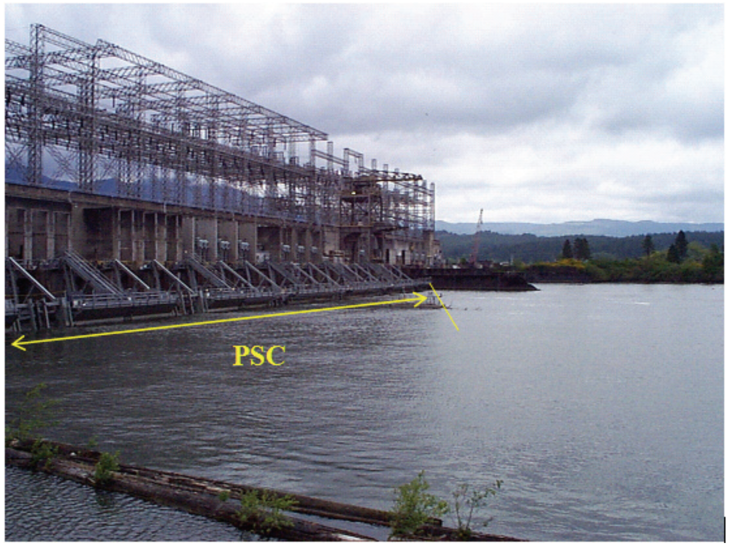

Figure 3.22. The Prototype Surface Collector at B1. (Photograph courtesy of M. Weiland)

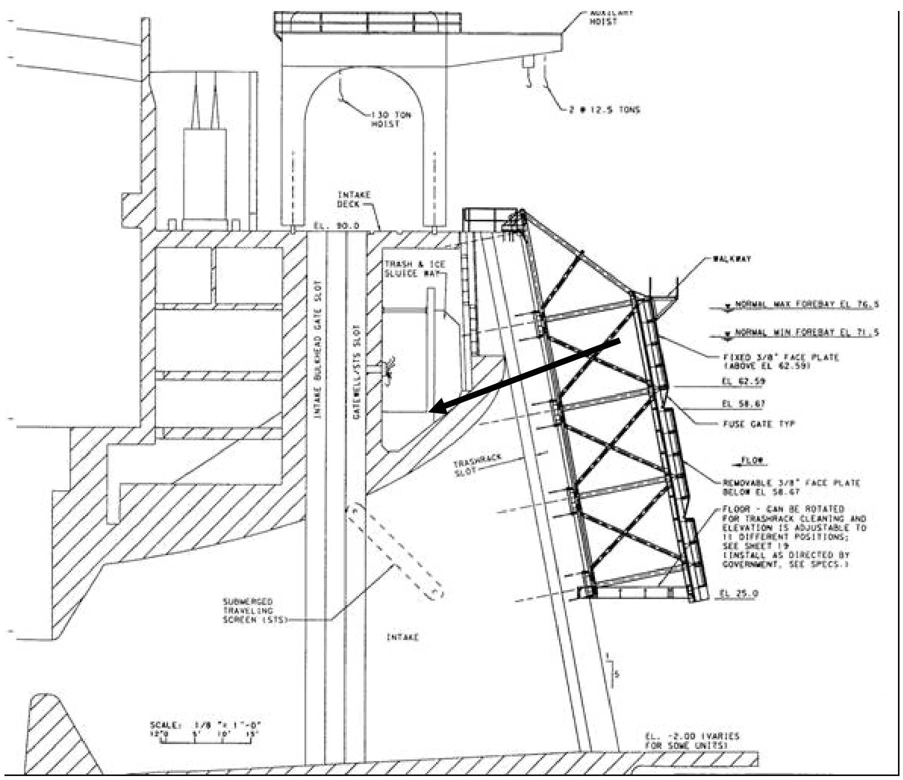

Figure 3.23. Side View of the PSC at B1. Arrow depicts flow into and through the PSC and into the turbine intake behind. PSC floor was actually installed at El. 30.5 ft, not 25.0 ft. Modified from Plate 4 in Harza and ENSR (1996a).

3.3.3.2 PSC Structure and Hydraulics

The PSC was retrofitted to the upstream face of B1 at units 1-6 (Table 3.8; Figures 3.22, 3.23, and 3.24). A detailed description of the PSC test structure can be found in Harza and ENSR (1996a). The PSC was located in the thalweg of the Columbia River at B1 (Figure 3.25). Vertical slots in the PSC in front of middle (B) intakes at each unit were configured to have 5-ft- or 20-ft-wide openings. Slot width during the evaluation was set according to a randomized block design. These widths were chosen to maximize differences in flows and velocities between the configurations to increase the likelihood of detecting differences in smolt response to PSC slot widths. PSC entrances were 40 to 46 ft deep depending on forebay level (the PSC floor was at El. 30.5 ft). The mean velocity at the entrance ranged from 3.8 to 8.3 fps, depending on slot width (Table 3.8). Flow through the entrances was 1,700 cfs for 5-ft slots and 3,300 cfs for 20-ft slots. Water velocity in the B1 forebay is generally higher in the north half than in the south half. Flow relatively close to units 1 to 6 (within 100 ft) had a southerly component. At the PSC, water velocities were about 4 to 7 fps and had a downward component (Figure 3.26).

Table 3.8. Characteristics of the PSC for 5-ft- and 20-ft-wide Entrances. The forebay was at El. 75 ft, the PSC floor was at El. 30.5 ft, and turbine discharge was 10,000 cfs / unit. Data are from the 1:25 scale physical model.

Characteristic	5-ft	20-ft
PSC flow (cfs)	1,700	3,300
Area (ft^2)	223	890
Velocity (fps)	7.1-8.3	3.8-4.6

Throughout the USACE Surface Bypass Program, physical models have been used to investigate specific design elements in the development process. For the PSC, several design elements were investigated on the B1 1:25 scale sectional and 1:40 scale general models. Also, Alternative A (described above) was modeled in the 1:40 scale physical model of B1. In general, developers observed some differences and similarities in water velocities for the 5-ft and 20-ft configurations for the conditions studied. Approach velocity was higher for the 20-ft than for the 5-ft configuration, although mean entrance velocities at the PSC slot were higher for the 5-ft than for the 20-ft width. Downward velocity components become pronounced deeper in the water column for the 20-ft than for the 5-ft. See Sweeney et al. (2007) for summary of hydraulic modeling for the PSC and Alternative A.

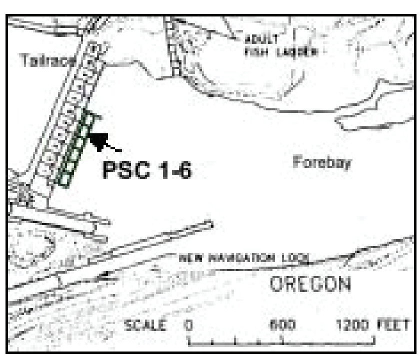

Figure 3.24. B1 Forebay and Powerhouse Showing the PSC Upstream of Turbines 1-6

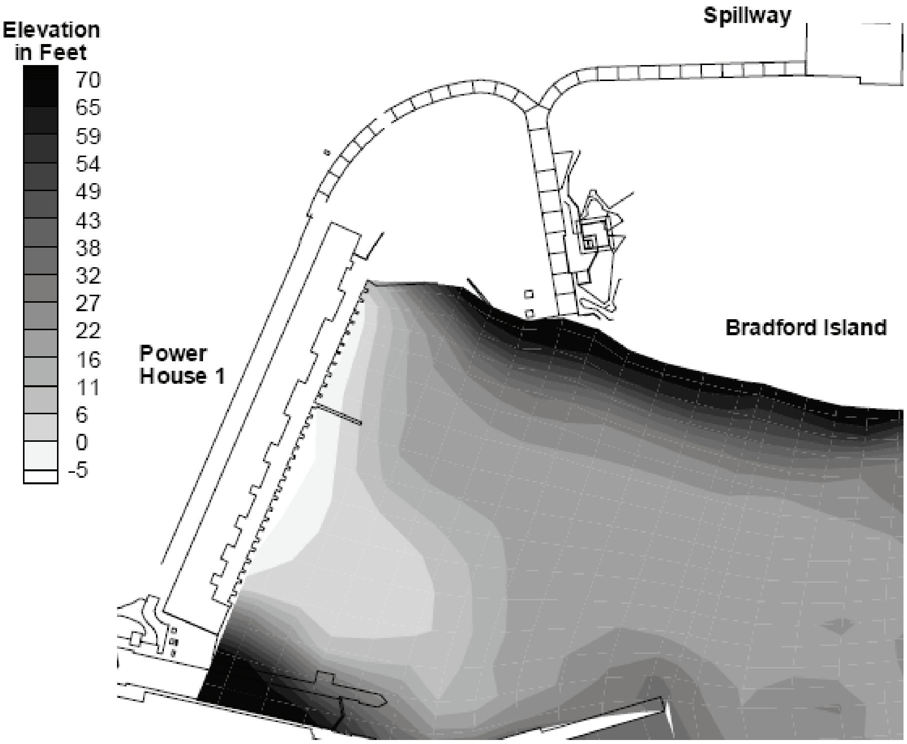

Figure 3.25. B1 Forebay Bathymetry Relative to Sea Level. Figure courtesy of C. Rakowski, PNNL, December 5, 2000.

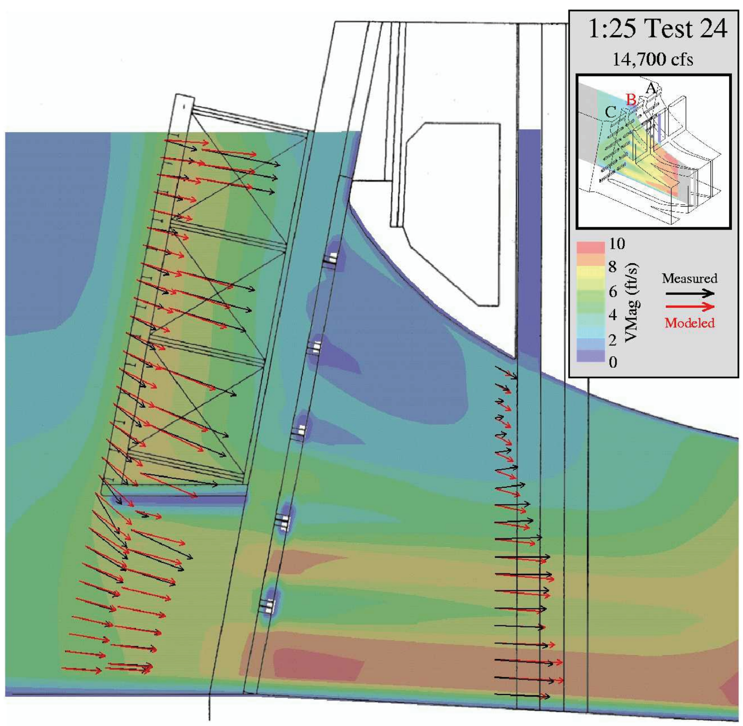

Figure 3.26. Sectional View of the PSC Showing Water Velocity from a CFD Model and a 1:25 Scale Physical Model. Figure courtesy of L. Ebner, CENWP.

3.3.3.3 PSC Operating Parameters

Operation of the PSC in 2000 involved the following parameters: PSC trashracks, entrance widths, entrance locations, turbine operations, sluiceway operations, forebay elevation, intake screens, and experimental design.

PSC Trashracks – The PSC trashracks were in place during the 1998 and 1999 tests. However, project maintenance did not require them because there are trashracks at the turbine intakes. Also, it was possible the PSC trashracks could cause some smolts to avoid the PSC entrances, so the PSC trashracks were removed for the 2000 test.

PSC Entrance Widths – During the 1998 and 1999 tests, PSC performance and fish behavior were compared for 5-ft vs. 20-ft-wide vertical entrances at PSC 3 and PSC 5. In 1998, the 20-ft entrance was more efficient than the 5-ft entrance in spring (Hensleigh et al. 1998 and Ploskey et al. 2001a). In summer 1998, Ploskey et al. (2001a) using hydroacoustics found that the collection efficiencies for 5-ft and 20-ft entrances were similar, while Hensleigh et al. (1998) using radio telemetry reported that the 20-ft entrance had much higher efficiency than the 5-ft entrance. Results from the 1999 hydroacoustic study (Ploskey et al. 2001b) were similar to those in 1998 (Ploskey et al. 2001a). Given the 1998-1999 results, it did not seem necessary to continue to compare 5-ft and 20-ft entrance widths in 2000. Thus, PSC entrance width was a constant 20 ft in 2000.

PSC Entrance Locations – The PSC had the capability for six entrances, one in front of the B-intake of each unit at units 1-6. To maximize PSC passage, all six entrances were opened.

Turbine Operations – For purposes of the PSC evaluation, turbine units 1-6 were priority units at B1 in 2000 to reduce hydraulic variability at the PSC. Units 1-6 were all operational for PSC tests in spring and summer 2000.

Sluiceway Operations – Open sluice gates at the B-slots behind the PSC entrances improved hydraulics inside the PSC, at least at the surface. Sluiceway flow probably had little effect on hydraulic conditions at depths below about 2 m within the PSC. For example, without an open sluice gate, surface flow was sometimes moving upstream and out of the PSC in the B slot. Upstream flow inside the PSC was considered undesirable because smolt passage through the PSC may be reduced. Thus, B-slot sluice gates behind each PSC entrance were opened with the weir crest at El. 72 ft for the 2000 study.

Forebay Elevation – Forebay elevation affected PSC inflows because the PSC was fixed in place. To minimize this effect on the PSC test in 2000, forebay elevation was constrained at ±1 ft around El. 74.5 ft.

Intake Screens – Intake screens were deployed at units 1-6 during the PSC evaluations.

<u>Biological Evaluations</u>

The 2000 PSC evaluation encompassed PSC efficiency and forebay fish migration patterns, including the following biological research methods:

- radio telemetry to determine species-specific PSC performance and movement patterns for yearling Chinook salmon and steelhead (Evans et al. 2001a, b)

- acoustic telemetry to study three-dimensional movement patterns and PSC performance for yearling Chinook salmon and steelhead (Faber et al. 2001)
- fixed hydroacoustics to estimate fish passage rates and determine PSC performance for the run at large during spring and summer (Ploskey et al. 2002a and 2002b)
- multi- and split-beam hydroacoustics to assess fish movements near the PSC (Johnson et al. 1999, 2000, and 2001)
- physical scale and computational fluid dynamics modeling to document forebay hydraulic conditions (Rakowski et al. 2001, 2005)

The key findings of the 2000 PSC evaluation presented below are organized by location, from approach in the forebay to passage at the dam.

The downstream migrants that entered the B1 forebay tended to follow the bulk flow as they approached the dam. For example, Faber et al. (2001) tracked acoustic-tagged fish within 100 m of the dam and found that "as fish approach the dam they hold to the thalweg…" (p. 19). More tagged fish approached the dam at units 4-6 than any other region at B1 (Evans et al. 2001a, b, p. 38; Faber et al. 2001, p. 20). However, fish generally ceased to follow the bulk flow once they encountered the dam.

Discovery efficiency[a] represents the percentage of tagged fish entering the B1 forebay that actually encountered the PSC flow nets. Radio telemetry estimates of discovery efficiency were 74% for steelhead and 63% for yearling Chinook salmon (Table 3.9). Acoustic telemetry estimates of discovery efficiency were 79% for steelhead and 90% for yearling Chinook salmon (Table 3.9). A relatively large percentage of fish entering the B1 forebay migrated within close proximity (< 6 m) to PSC entrances at Units 1-6 even though passage was usually possible at the entire powerhouse, units 1-10. Thus, most smolts seemingly had opportunity to discover the PSC flow nets.

Table 3.9. Discovery Efficiency Estimates based on Radio and Acoustic Telemetry at B1 in 2000. Sample sizes of tagged fish are given in parentheses (number detected within 6 m of a PSC entrance out of the total entering the B1 forebay). Radio telemetry data were obtained from Evans et al. (2001; p. 27). Acoustic telemetry data were obtained from Faber et al. (2001; modified from data on p. 15).

Species	Radio Telemetry	Acoustic Telemetry
Steelhead	74% (356 of 481)	79% (110 of 139)
Yearling Chinook	63% (341 of 545)	90% (28 of 31)

[a] Discovery efficiency is estimated by dividing the number of tagged juveniles detected within 6 m of the PSC entrances by the total number of tagged fish entering the B1 forebay.

The vertical distribution of tagged and untagged smolts approaching and encountering the PSC was surface oriented (Evans et al. 2001a, b; Ploskey et al. 2001a and 2002b). Depth of approach of radio-tagged fish to the PSC was determined by the vertical position of the antenna recording the first detection for a particular tagged specimen. The vertical distribution of radio-tagged fish was classified as shallow (< 6.5 m) or deep (> 6.5 m). Radio-tagged steelhead[a] were distributed shallower than yearling Chinook salmon (steelhead 76% shallow and 24% deep; Chinook salmon 53% shallow and 47% deep; Evans et al. 2001a; p. 32). In hydroacoustics evaluations at the face of the PSC (1-3 m away) in 2000, Ploskey et al. (2002b; p. xxi) detected 92%-99% of the targets above the floor of the PSC (El. 30.5 ft) in spring. In summer, 85%-96% were above the depth of the PSC floor. The vertical distribution of fish approaching the PSC corresponded well with the vertical position of the PSC entrances (Figure 3.27).

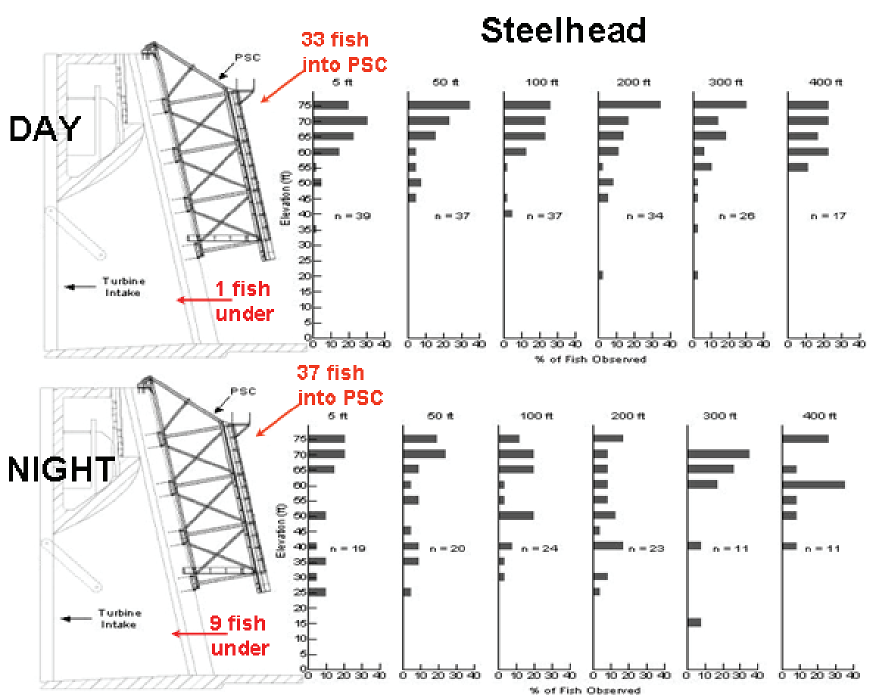

Figure 3.27. Vertical Distribution and Passage of Radio-Tagged Juvenile Steelhead during Day (Top) and Night (Bottom) at the B1 PSC in 2000. Figure from Faber et al 2001.

Radio telemetry estimates of entrance efficiency[a] were 60% for steelhead and 72% for yearling Chinook salmon (Table 3.10). Acoustic telemetry estimates of entrance efficiency were 64% for steelhead and 79% for yearling Chinook salmon (Table 3.10). Entrance efficiency was higher for yearling Chinook salmon than for steelhead. Many tagged fish that appeared to get close enough to encounter (discover) the PSC flow nets seemed to eventually pass through the structure, but others apparently passed elsewhere (under the PSC, Units 7-10, or back out of the B1 forebay).

Three general movement patterns were displayed by radio- and acoustic-tagged fish: direct passage, searching, and milling. Direct passage was characterized by short forebay residence time (< 1 h) before

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[a] Entrance efficiency is estimated by dividing the total number of tagged juveniles entering the PSC by the total number detected within 6 m of the PSC entrances.

passing into B1. Searching was displayed as active movement back and forth along B1, including the PSC, resulting in longer residence times (1-4 h) than observed for direct passage fish. Milling was defined as relatively long residence times (> 4 h). Of the radio-tagged fish, 31% of the steelhead (61 of 200) and 47% of the Chinook salmon (100 of 214) passed directly, i.e., they passed at the first PSC entrance they encountered (Evans et al. 2001a, b). Results were similar for acoustic-tagged fish. Acoustic-tagged steelhead and Chinook had a higher percentage of direct passage at night than they did during the day. Non-direct movement was also exhibited in the hydroacoustic data (Johnson et al. 2001).

Table 3.10. Entrance Efficiency Estimates based on Radio and Acoustic Telemetry at B1 in 2000. Sample sizes of tagged fish are given in parentheses. Radio telemetry data were obtained from Evans et al. (2001a; p. 27, revised June 12, 2001). Acoustic telemetry data were obtained from Faber et al. (2001; modified from data on p. 15).

Species	Radio Telemetry	Acoustic Telemetry
Steelhead	60% (214 of 356)	64% (70 of 110)
Yearling Chinook	72% (246 of 341)	79% (22 of 28)

Fish tracked with multi-beam hydroacoustics tended to move upstream and downstream equally, indicating milling behavior (Johnson et al. 2001). Milling behavior was also revealed as fish movements became more variable the closer the fish got to the PSC. Movements of fish tracked with hydroacoustics in the region 18 m in front of the PSC entrance at Unit 3 were generally obliquely downstream and southerly toward the dam (Johnson et al. 2001). In addition, Evans et al. (2001; p. 31) reported "that, in general, both steelhead and Chinook salmon moved laterally from north to south along the face of the PSC before passing into it."

Some acoustic-tagged fish and fish tracked with multi-beam hydroacoustics exhibited positive rheotaxis within ~ 6 m of PSC entrances (Faber et al. 2001; Johnson et al. 2001). That is, when some fish got relatively close to the PSC entrances they apparently turned and oriented upstream into the flow. Also, Johnson et al. (2001) observed that fish swam strongly upward in the water column in response to the downward component of the PSC flow net at the sample site at Unit 3. As determined by acoustic telemetry, fish classified as milling held at the sides of the B1 forebay and were oriented into the flow. Positive rheotaxis indicated that fish responded to environmental stimuli at the PSC, probably related to hydraulic conditions.

The forebay residence time of tagged fish that passed at B1 was about 4 to 10 h. Yearling Chinook salmon passed the dam a little faster (by a few hours) than steelhead. Some tagged fish resided for a considerable amount of time in the forebay before passing (e.g., several days), as indicated by the relatively low median values compared to the means.

In spring 2000, the fish collection efficiency[a] of the PSC was estimated on a species-specific basis for yearling migrant steelhead and Chinook salmon using radio and acoustic telemetry and for the run at large using fixed-location hydroacoustics (Table 3.11). During the hydroacoustic summer study, subyearling Chinook salmon dominated the out-migration. (The study ended before shad became prevalent in the

▪ [a] Fish collection efficiency is defined as PSC passage divided by PSC passage plus passage under the PSC.

forebay.) Thus, the hydroacoustic results for summer can be ascribed to subyearlings. Species-specific estimates of collection efficiency are important to decision-makers because different species may respond differently to smolt protection measures.

Radio telemetry estimates of collection efficiency were 82% for steelhead and 76% for yearling Chinook salmon (Table 3.11). Acoustic telemetry estimates of collection efficiency were 88% for steelhead and 96% for yearling Chinook salmon. For the purposes of passage modeling and planning, we believe the species-specific collection efficiency estimates from radio telemetry should be used, because the relatively large sample sizes for radio telemetry likely yielded more precise estimates than those from acoustic telemetry.

Table 3.11. Fish Collection Efficiency Estimates based on Hydroacoustics, and Radio and Acoustic Telemetry at B1 in 2000. Sample sizes are in parentheses. Hydroacoustic data from Ploskey et al. (2002b); adjusted for passage into the sluiceway behind the PSC entrances which was not sampled by hydroacoustics. Radio telemetry data from Evans et al. (2001; p. 30, revised June 12, 2001). Acoustic telemetry data from Faber et al. (2001; p. 15).

Population	Season	Hydroacoustics	Radio Telemetry	Acoustic Telemetry
Steelhead	Spring	----	82% (200 of 258)	88% (70 of 80)
Yearling Chinook	Spring	----	76% (214 of 312)	96% (22 of 23)
Run-at-Large	Spring	83%	----	----
Subyearling Chinook	Summer	84%	----	----

Hydroacoustic estimates of collection efficiency (unadjusted for sluiceway passage behind the PSC) were 72% for both spring and summer (Figure 3.28). Note that the hydroacoustic process underestimated collection efficiency because passage into the sluiceway was not sampled at the gates open behind the PSC entrances (B-slots). The radio telemetry data, however, indicated that roughly 50% of PSC passage for both tagged species combined was via the sluiceway (S. Evans, pers. comm.). Thus, after adjusting the data for 50% sluiceway passage in the PSC, the hydroacoustic estimates of collection efficiency were 83% for spring and 84% for summer 2000 (Table 3.11).

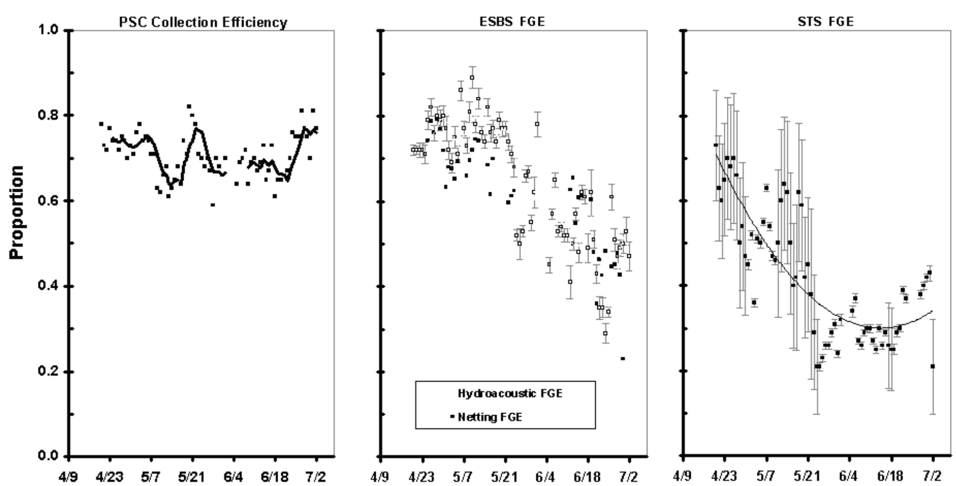

Figure 3.28. Daily PSC Fish Collection Efficiency (Left Panel) Compared to Fish Guidance Efficiency for a Prototype Extended Length Bar Screen in Unit 8 (Middle Panel) and a Submersible Traveling Screen in Units 7, 9, 10 (Right Panel). From Ploskey et al. (2002b)

PSC fish collection effectiveness[a], as determined in the radio telemetry study, was 2.49 for steelhead and 2.30 for yearling Chinook salmon (Evans et al. 2001; p. 30, revised June 12, 2001). Acoustic telemetry estimates of effectiveness were 2.63 for steelhead and 2.87 for yearling Chinook salmon (Faber et al. 2001; p. 15). Based on hydroacoustics, PSC effectiveness was 2.15 in spring and 2.23 in summer. An effectiveness of 2 means that the percentage of fish moving into the PSC out of total passage was twice the percentage of water passing into the PSC. Trends in effectiveness were similar to those of collection efficiency because the percentage of water passing into each PSC entrance was fairly uniform.

The fish budgets for steelhead and yearling Chinook salmon based on radio telemetry were linked to the PSC performance metrics (Figure 3.29). This figure summarizes B1 passage and PSC performance for radio-tagged fish. We used radio telemetry data for this summary rather than acoustic telemetry because larger sample sizes were available for radio telemetry.

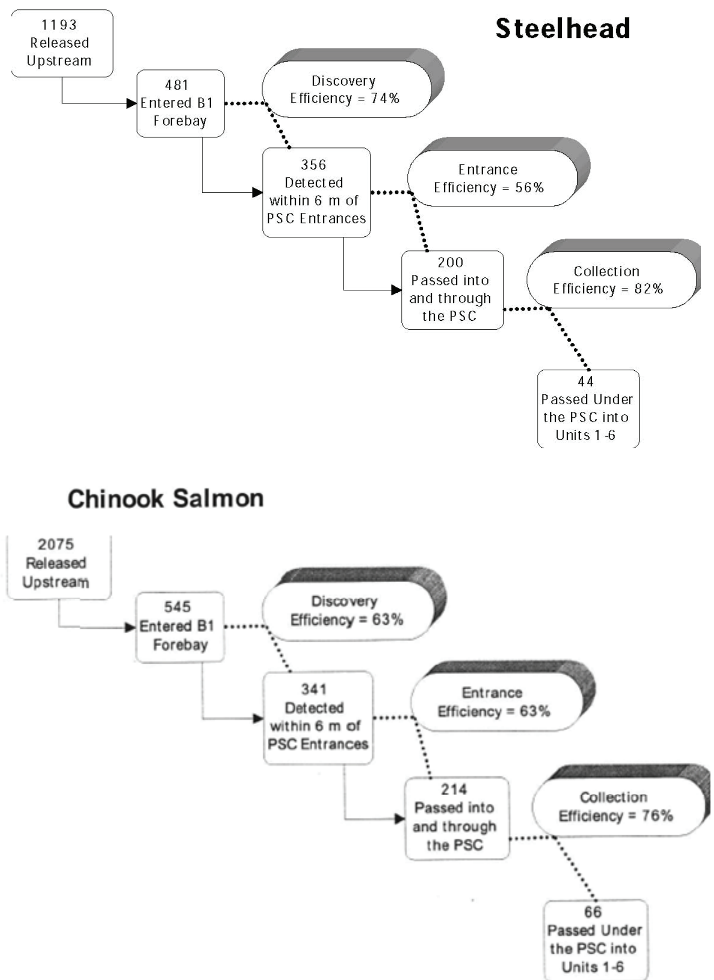

Figure 3.29. Fish Budgets Reflecting Discovery, Entrance, and Fish Collection Efficiencies for Radio-Tagged Steelhead (Top) and Yearling Chinook Salmon (Bottom). The fish budgets are based on data from Evans et al. (2001a, b), prior to the revisions in the data shown in Table 3.10.

[a] Fish collection effectiveness is defined as PSC fish collection efficiency divided by proportion of water passing into the PSC out of total discharge at units 1-6.

The fish collection efficiency of the PSC remained high in both the spring and summer seasons in 2000, unlike the fish guidance efficiency of the extended length bar screens and submersible traveling screens, which declined significantly from spring through summer (Figure 3.28). The daily collection efficiency data for the PSC varied between 60% and 80%. Fish guidance efficiency for the two types of intake screens was about 20% to 90%. The decline in summer for intake screen guidance efficiency is a recurring pattern (Ferguson et al. 2005).

3.3.3.4 Summary

Based on the collective data during the 1998-2000 PSC evaluation period (summarized by Johnson and Carlson 2001), researchers found that the surface bypass concept as applied at B1 was an efficient way to collect juvenile salmonids and minimize turbine passage. Fish collection efficiency estimates from hydroacoustics, radio telemetry, and acoustic telemetry methods comported reasonably well. The highest quality and most applicable data for fish collection efficiency, because of large sample sizes and the PSC covered units 1-6 are from the 2000 evaluation. For the purposes of planning and analysis for constant turbine operations, at one slot opening, the following fish collection efficiency estimates should be used:

Yearling Chinook salmon	76%
Steelhead trout	82%
Subyearling Chinook salmon	84%

Fish collection efficiency was similar between spring and summer, i.e., it did not decrease in summer but stayed largely unchanged while the run composition changed. This is not true of other smolt bypass approaches that have decreasing efficiency as the season progresses. Fish collection efficiency for the B1 PSC was higher than that for the surface bypass and collector SFO at Lower Granite Dam, and comparable to that for the Wells Dam SFO. Extending the PSC to Units 1 and 2 in 2000 was worthwhile because the surface bypass entrances at Units 1 and 2 passed a substantial proportion of total PSC fish passage (23% to 28%). According to radio telemetry data from 2000, the PSC would have increased fish passage efficiency at Bonneville Dam 18% for steelhead and 10% for Chinook salmon had it been a functional bypass system. The PSC was twice as effective (percentage fish divided by percentage water) as spill at passing fish at Bonneville Dam in 2000.

3.3.3.5 After the PSC

The B1 PSC showed promise as a powerhouse retrofit SFO, but it was not followed by a full production structure. The main reasons for this included

- uncertainty about fish response to forebay flow fields from a ramped entrance structure
- complexity of the conveyance and outfall structures
- uncertainty of fish injury rates at high flow outfalls
- commitment to the B2 Corner Collector and associated designation of B2 as the priority powerhouse at Bonneville Dam
- cost (~$200M)

Future SFO development at B1, however, is a possibility. Such SFO work could involve the B1 Sluiceway where the wall for the juvenile bypass screen system in the sluiceway channel is scheduled for removal in 2007. Other sluiceway improvements would be to increase sluiceway discharge, install automated gates to follow forebay elevation to produce a constant discharge, and evaluate fish survival at the existing outfall to examine if a new outfall is necessary. There are also possibilities for a new powerhouse retrofit SFO. Options would entail new conveyance and outfall structures, perhaps for a partial or full powerhouse Alternative A. Another idea is a B1 corner collector SFO with or without an associated behavioral guidance structure. Preliminary engineering is available for most of these options. We strongly recommend evaluating changes to the sluiceway system including its efficiency and effectiveness and fish survival after improvements are made. The survival study should include reference releases of fish from the existing outfall and potential alternative outfalls.

3.3.3.6 Conclusions

The PSC evaluations demonstrated the efficacy of a powerhouse retrofit SFO for B1. Lessons learned from the PSC will be applicable to any future SFO development efforts at B1.

3.3.4 B2 Corner Collector

3.3.4.1 Introduction

At Bonneville Second Powerhouse, the ice and trash sluice chute has been developed as a surface flow outlet for juvenile salmonids called the B2 Corner Collector (B2CC). There have been two phases to development pre-B2CC and post-B2CC. In the pre-B2CC era during the 1980s and 1990s, managers were motivated to study the ice-trash sluice chute as a non-turbine passage route by the substandard fish guidance efficiency of the intake screen bypass system at B2 (e.g., Monk et al. 1999a). During this time, the sluice chute was not typically operated for juvenile passage. However, based on forebay hydraulic patterns and fish distribution observations by USACE biologists,[a] a strategy was developed to use the sluice chute as a surface flow outlet (Figure 3.30 courtesy of G. Ploskey)

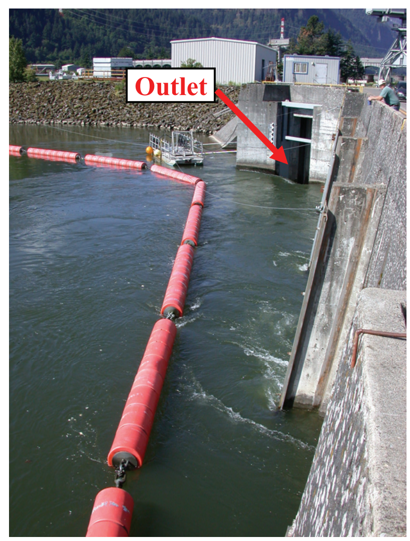

Figure 3.30. Photo of the B2CC.

The USACE engineering process commenced in 1995 to develop a formal SFO at B2. In the feasibility phase of the USACE process, Harza and ENSR (1996a,b), under direction of the Portland District, identified a number of surface flow outlet alternatives for B2. Development of the sluice chute was one of the alternatives. INCA et al. (1997) used physical scale models to study hydraulic and structural aspects of the sluice chute as a surface flow outlet from biological and engineering perspectives. Consideration was also given to a physical guidance device at the beginning of the B2 forebay channel (CH2M-Hill et al. 1998). In 1997 and 1998, the sluice chute was opened for biological research using an improved monitoring methodology to re-evaluate its passage potential. Given the encouraging results of

[a] The late Jim Kuskie, Project Biologist for Bonneville Dam, noted that juvenile salmonids passed into the ice and trash sluice chute when it was opened during migration seasons in the 1980s.

the 1998 biological studies (presented below), fisheries managers and the Corps committed to development of the B2CC. In the design phase of the engineering process, the District performed a B2CC outfall type and site selection study. Concurrently, Johnson et al. (2000) studied biological and hydraulic characteristics of high flow outfalls (> 1,000 cfs), like the one being developed at the time for the B2CC. The engineering phase concluded with the Design Documentation Report by the District. ENSR et al. (1999) reviewed alternatives for dewatering and outfall location at B1; some of the findings were applicable to B2. The construction phase for the new entrance gates, conveyance channel, and outfall for the B2CC was completed in 2004. After this, PNNL and USGS evaluated B2CC biological performance during 2004 and 2005. Today, the B2CC is a permanent, functional surface flow outlet that is routinely operated as a complement to the intake screen system for smolt protection at B2. The purpose of this section is to describe B2CC development in detail.

3.3.4.2 Description of the Original B2 Sluice Chute

The ice and trash sluice chute is located on the southwest corner of the B2 powerhouse. It is oriented 45 deg off the horizontal axis of the powerhouse, a purposeful design to pass ice and trash from the forebay to the tailrace below the dam. The entrance is 15 ft wide. Bottom and top vertical weir gates (Figure 3.31) controlled flow into the sluice chute. The bottom weir gate rested on a concrete sill at El. 52 ft. It could be raised (undershot flow) to El. 61 ft. The top weir gate can be lowered (overflow) to El. 59.5 ft. Typically, the top gate is lowered to dog-off points that result in the weir crest at El. 61 or 68 ft. After passing over the weir gate, water drops about 45 ft to the channel floor at El. 29 ft (Figure 3.31). The chute channel turned 45 deg to the right about 25 ft downstream of the weir gate. The radius of the turn in the 15-ft-wide channel was about 32 ft, which corresponded to a curvature of about 2 diameters. The distance from the curve to the terminus of the chute (outfall) was about 400 ft. Sluice chute discharge was about 3,000 cfs with the weir gate at El. 61 ft and the forebay at El. 75 ft.

3.3.4.3 B2 Forebay Hydraulic Conditions

Hydraulic conditions in the B2 forebay and at the sluice chute entrance are important to the surface flow outlet there. From qualitative observations in both the field and the 1:40 scale physical model, B2 hydraulics were unsteady with eddies and boils appearing sporadically. The dominant feature of the forebay hydraulics is the large eddy that forms in the entire half of the forebay in front of the sluice chute (Figure 3.32). This eddy turns counterclockwise and increases in intensity as powerhouse loading increases. It dissolves when one or two units are operating. The B2 forebay eddy serves to concentrate fish and debris at the southwest corner of the forebay at the sluice chute entrance.

Limited water velocity measurements were available from physical model (1:40 general) or field work in the forebay near the B2 sluice chute entrance. With the weir at El. 61 ft and forebay at El. 73 ft, calculated flow was about 2,800 cfs. Entrance velocity varied by depth; velocities were faster than shown at El. 67 and 70 ft and less for El. 64, 61, and 58 ft. Overall, entrance velocities ranged from 9 to 16 fps (Figure 3.33).

During model investigations, engineers observed distinctive hydraulic patterns with and without turbine intake extensions (TIEs). With the TIEs removed, lateral movement across the face of the powerhouse was smooth with minimal disruption before encountering the "zone of influence" of the collector entrance. With the TIEs installed, significant amounts of dye become entrained in eddies between adjacent TIEs and general turbulence levels increased.

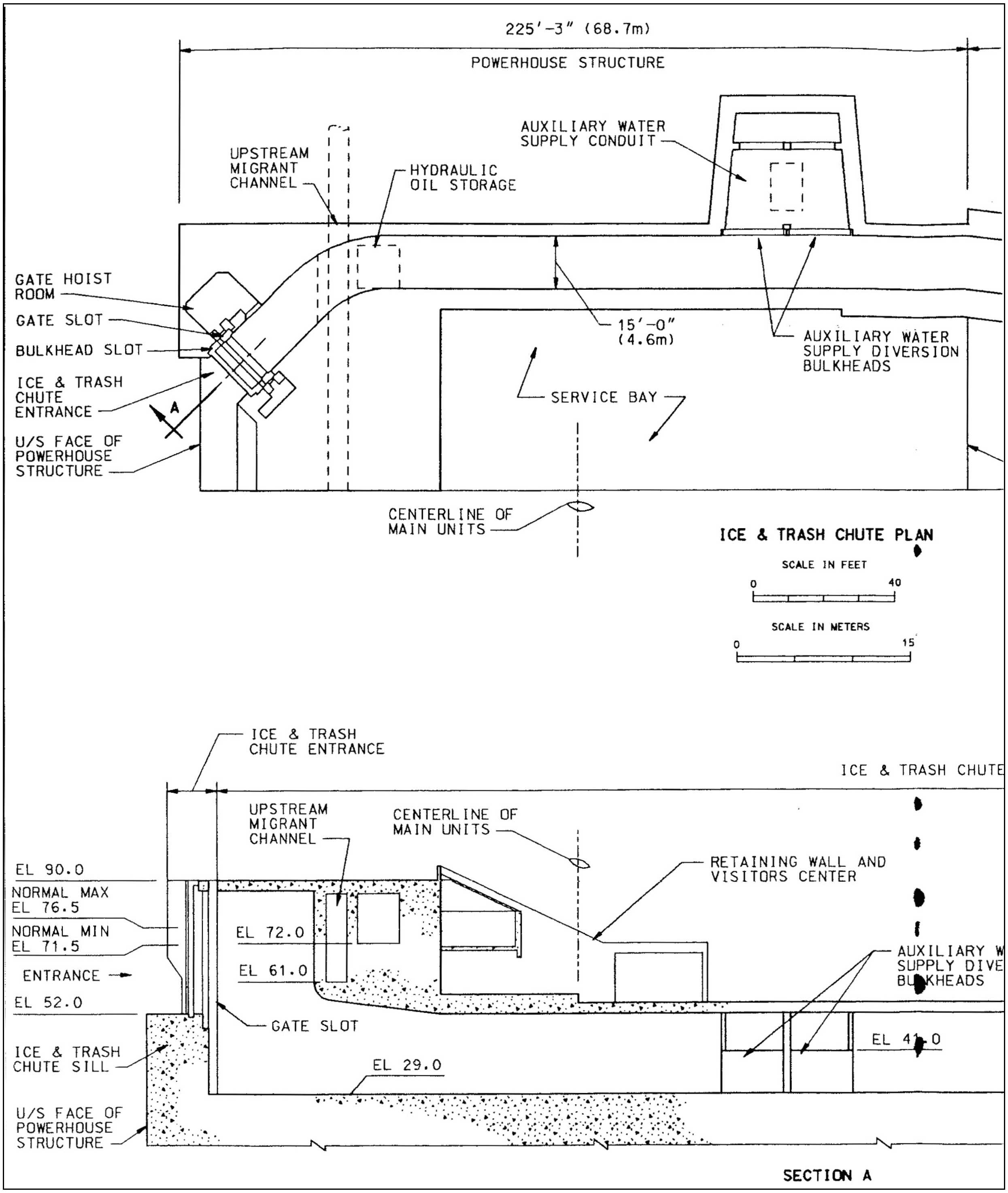

Figure 3.31. Top and Side Views of the Old Sluice Chute at B2. Modified from Plate 2 in INCA et al. (1997).

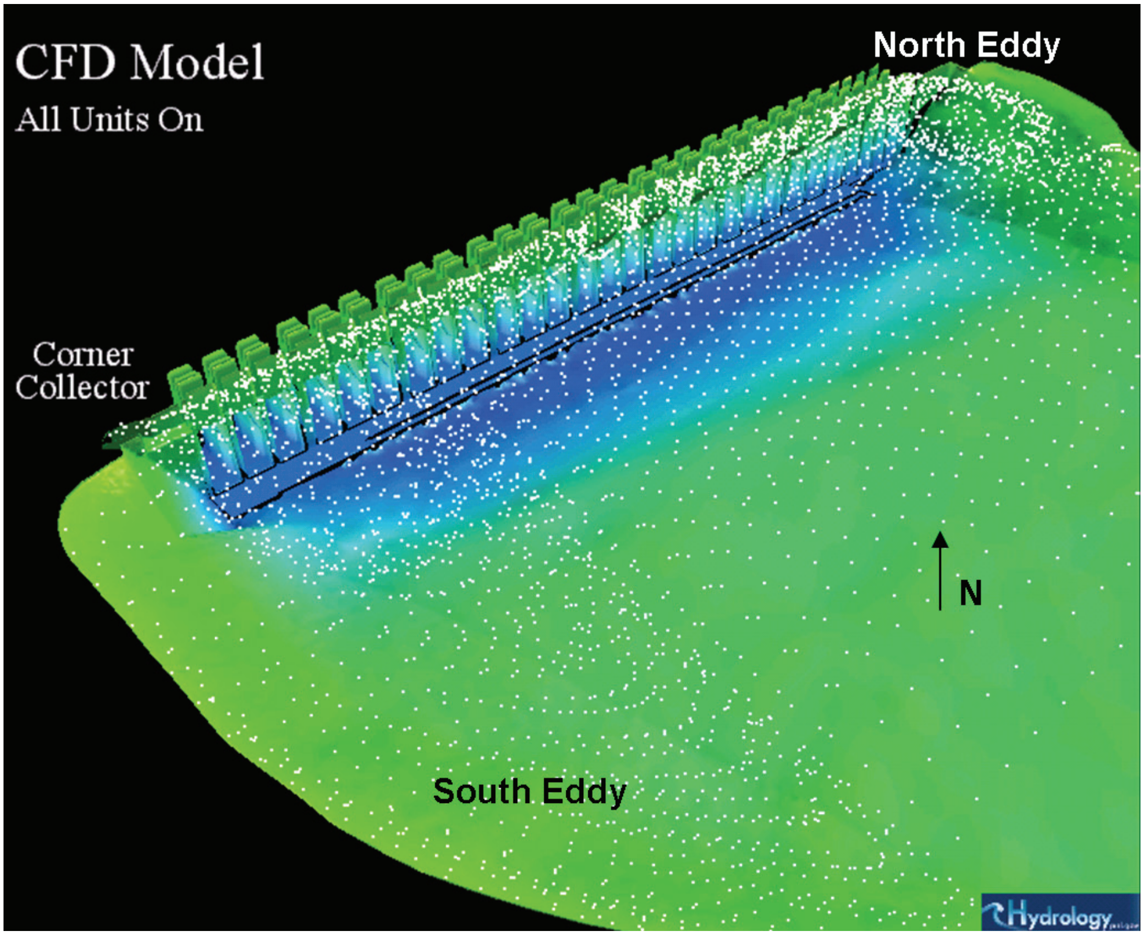

Figure 3.32. Computational Fluid Dynamic Model Display of Bonneville Powerhouse 2 Forebay Circulation. Dots represent particles suspended in surface flow and concentrations indicate flow patterns such as upwelling at the dam face and north and south eddies.

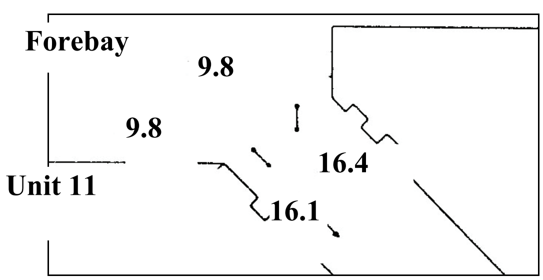

Figure 3.33. One-Dimensional Spot Velocities (fps) as Measured at the B2 Sluice Chute Entrance in the 1:40 Physical Model at the Engineering Research and Development Center. Weir gate was at El. 61 ft, forebay was at El. 73 ft, and calculated B2 sluice chute flow was at 2,800 cfs.

3.3.4.4 Early Studies: 1980s

INCA et al. (1997) summarized research conducted in the 1980s at the B2 sluice chute with respect to its potential as a surface bypass. Studies by Nagy and Magne (1986), Magne (1987a,b,c), Magne et al. (1989), and Stansell et al. (1990) documented that the B2 sluice chute passed substantial numbers of juvenile salmonids. None of these studies, however, was able to make a direct estimate of sluice chute efficiency (i.e., sluice chute passage relative to passage elsewhere at the B2 powerhouse) because of sampling difficulties. Clearly the potential was evident, but questions remained regarding forebay collection, conveyance, and outfall conditions.

3.3.4.5 Baseline Studies at the B2 Sluice Chute: 1990s

The hiatus in research on the B2 sluice chute between 1989 and 1995 ended with establishment of the Surface Bypass Program for Bonneville Dam. To provide baseline data for the new program, forebay distribution studies were conducted in 1995 (see Section 2). In addition, the B2 sluice chute was tested as a prototype SFO. In 1996, 12 radio-tagged yearling and 25 subyearling Chinook salmon were contacted in the vicinity of the sluice chute entrance, but none apparently entered it (Holmberg et al. 1996). That same year, fixed hydroacoustic estimates of fish passage at the sluice chute were problematic, because of excessive acoustic noise associated with turbulent surface currents created by the turbine intake extensions (Ploskey et al. 1998). In 1997, BioSonics (1998) sampled fish passage at the sluice chute and Turbine Intake 11A to provide baseline data on chute efficiency. They also reported excessive acoustic noise from the TIEs with the weir gate at El. 61 (~3,300 cfs), but not at El. 68 (~1,100 cfs). INCA et al. (1997) recommended that the sluice chute be evaluated as a prototype corner collector in 1998, with the TIEs removed to allow for hydroacoustic monitoring of fish passage into the sluice chute with the gate at El. 61.

The most influential biological test of the original B2 ice and trash sluice chute took place in 1998. During the 1998 test, the weir crest was at El. 61 ft (Figure 3.31). Thus, the entrance was 15 ft wide and about 14 ft high with discharge of 3,000 cfs, depending on forebay level. The approximate mean velocity upstream of the gate was 15.4 fps. Turbine intake extensions were removed at Units 11-14 to reduce turbulence at the sluice chute entrance. Removal of the TIEs also made the southerly, lateral flow lines at the face of powerhouse Units 11-14 less variable and more uniformly directed to the sluice chute entrance weir. In 1998, the B2 sluice chute was opened and closed according to a randomized block experimental design to compare passage rates at the adjacent units (Unit 11-13). The B2 sluice chute and B2 intakes were monitored and evaluated using fixed radio telemetry and fixed hydroacoustics.

In the 1998 radio telemetry study, about ¾ of the steelhead and ½ of the yearling Chinook salmon that passed B2 were detected within 10 ft of the B2 sluice chute entrance; this means discovery efficiency (DE) was high (overall DE = 61%; Table 3.12). After relatively few detections of PIT tagged fish for a survival study at The Dalles Dam just upstream were detected in the B2 juvenile bypass system, the sluice chute was closed most of summer 1998, so few data on subyearlings could be collected.

In 1998, entrance efficiency (# entering/total # within 10 ft of antenna detection range), according to radio telemetry data, was also high (Table 3.12). It was 71% for steelhead (42 of 59) and 76% for yearling Chinook salmon (25 of 33). Since water velocity within 10 ft of the B2 sluice chute entrance was relatively high (~12 fps at the weir gate), the radio telemetry detection zone was presumably this was within the B2 sluice chute flow net. Thus, these data indicate that relatively few radio-tagged fish avoided the B2 sluice chute entrance.

Table 3.12. Results from monitoring radio-tagged fish passage at the B2 sluice chute and intake screen system at B2 in 1998. Discovery efficiency is # within 10 ft of B2 sluice chute divided by total. Entrance efficiency is # into B2 sluice chute divided by # within 10 ft. Forebay collection efficiency is # into B2 sluice chute divided by total B2 passage. CBE is B2 sluice chute plus guided fish passage divided by total B2 passage. n/a = not applicable. Data are from Hensleigh et al. (1998).

Metric	CH1		ST		Total	
B2 sluice chute entrance	open	closed	open	closed	open	closed
W/in 10 ft B2 sluice chute	59	n/a	33	n/a	92	n/a
Into B2 sluice chute	42	0	25	0	67	0
Guided	17	25	10	20	27	45
Unguided	22	25	35	46	57	71
Total into B2 and B2 sluice chute	81	50	70	66	151	116
Discovery efficiency	0.73	n/a	0.47	n/a	0.61	n/a
Entrance efficiency	0.71	n/a	0.76	n/a	0.73	n/a
Forebay collection efficiency	0.52	n/a	0.36	n/a	0.44	n/a
CBE	0.73	0.50	0.50	0.30	0.62	0.39

Overall, B2 sluice chute efficiency for radio-tagged fish relative to passage at the entire B2 powerhouse was impressive: 52% for steelhead and 36% for yearling Chinook salmon (Table 3.12). Given the relatively small proportion of flow entering the B2 sluice chute (~2%), effectiveness (B2 sluice chute efficiency/percent B2CC flow) of the B2 sluice chute was about 26 for steelhead and 18 for yearling Chinook salmon. Effectiveness this high had not been observed at any other surface bypass in the region (see Dauble et al. 1999 for a review).

Comparing combined bypass efficiency [CBE = (B2 sluice chute +guided)/total at Units 11-13] with the B2 sluice chute open and closed showed the positive effect of the B2 sluice chute. CBE was higher for steelhead with the B2 sluice chute open than with it closed (73% open vs. 50% closed; Table 3.12). The same trend held for yearling Chinook salmon (50% open vs. 30% closed; Table 3.12). Clearly, the operating the B2 sluice chute resulted in more fish passing B2 through non-turbine routes than with it closed (23% more for steelhead and 20% more for yearling Chinook salmon; Table 3.12). The B2 sluice chute did not “rob” fish that would otherwise have been guided by the intake screens because CBE was so much higher with the B2 sluice chute open than closed. In fact, the data indicated that the B2 sluice chute passed many fish that would otherwise have gone through B2 turbines.

Also in 1998, Ploskey et al. (2001a) used hydroacoustics to monitor fish passage into the sluice chute and Intakes 11B, 12B, and 13B. The trend in CBE for the sluice chute and Units 11-3 for the run-at-large was consistent with that observed for radio tagged fish; CBE was significantly higher with the sluice chute open than closed (Table 3.13). Sluice chute efficiency relative to Units 11-13 was 83% in spring and 81% in summer. Sluice chute effectiveness was 5.8 in spring and 4.6 in summer. When extrapolated to the entire powerhouse, effectiveness was about 12-16. These values are less than those estimated using radio telemetry data, but are still high relative to other regional surface bypasses.

Table 3.13. Combined Bypass Efficiency for the Sluice Chute and Screens at Units 11-13 when the Sluice Chute was Open and Closed in Spring and Summer 1998. Based on hydroacoustic data from Ploskey et al. (2001a, p. 35).

Sluice Chute	Spring	Summer
Open	0.90	0.90
Closed	0.55	0.30

Overall, results from the 1998 radio telemetry and hydroacoustic studies indicated strong potential for the B2 sluice chute to successfully collect juvenile salmonids because of their distribution in the forebay relative to the dominant flow patterns. Juvenile salmonids were concentrated in relatively shallow water (~45 ft deep) on approach over the forebay shelf. Many remained surface-oriented and were guided along the face of the dam toward the B2 sluice chute in the large eddy in the southwest corner of the forebay. This eddy flow, in conjunction with the 45 deg orientation of the B2 sluice chute entrance relative to the face of the dam, seemed to cause high discovery efficiencies (~61%). Presumably gradual acceleration into the B2 sluice chute entrance until juvenile salmonids were entrained in the high velocity B2 sluice chute flows probably caused the high entrance efficiencies (~73%). Juvenile salmonids that did not enter initially could have multiple discovery and entry opportunities because of the large forebay eddy. Thus, forebay collection efficiency was high (~44%) given the small amount of B2 sluice chute flow (~3% of total B2). Conveyance and outfall issues, however, remained to be resolved. From the results of the 1998 studies, however, the fisheries managers recommended development of the B2 sluice chute as a permanent surface flow outlet. This SFO would be called the B2 corner collector.

3.3.4.6 High Flow Outfall Studies at B2

Guidelines for high flow outfalls were critical to development of the B2 corner collector outfall, as well as the surface flow outlets elsewhere. The NMFS outfall criterion for mean jet entry velocity is < 25 fps. However, outfall discharges for SFOs at mainstem dams (without dewatering) have jet entry velocities much greater than 25 fps. Thus, there was a need to estimate fish injury and survival rates under various outfall conditions to establish high flow outfall guidelines.

Research applicable to high flow outfalls was conducted by Normandeau et al. (1996). They used balloon tags at the sluiceways at B1 and B2 to study injury and mortality rates for hatchery yearling Chinook salmon (n = 100 each). Control fish were not included in these preliminary investigations conducted in October 1995. B1 sluice discharge was about 200-300 cfs, while B2 sluice discharge was about 650 cfs. At the B1 sluice outfall, 7 of 100 fish were not recaptured, and 4 of the 7 were probably preyed upon based radio-tracking information. The authors noted that predation did not seem to be a problem during their October study at the B2 sluice outfall. Injury rates were low at both sluices (1 of 93 recaptured fish and 1 of 90 at B1 and B2, respectively).

In 1999, a formal project within the Anadromous Fish Evaluation Program was established to develop high flow outfall guidelines. ENSR and INCA (2000) calculated energy dissipation, strain, deceleration and other rates, strain rates to support test design for the high flow outfall research in a laboratory flume. Johnson et al. (1999) offered preliminary guidelines, but concluded that more research was necessary before they could be finalized. In 2001, Normandeau et al. (2001) performed balloon tag studies at the

B2 sluice chute outfall that showed low (< 1%) injury rates. The high flow outfall research culminated in the following guidelines:

Locate where

- Receiving water velocities are greater than 4 fps, unless site-specific velocities with an operating high flow outfall are determined to be acceptable.
- Receiving water characteristics, especially depth in combination with magnitude and trajectory of outfall discharge, are sufficient to prevent mechanical fish injury if they contact the bottom.
- Eddies or back-rollers in the pre-outfall receiving water are minimal.
- Predators are not concentrated near the outfall plume.
- Adult migration (fishway entrances, shorelines, or known adult migration paths) will not be deleteriously affected by the high flow outfall discharge and plume.
- Project operations do not produce changes in hydraulic conditions that result in violations of other guidelines.

Design so that

- Mean entry velocity for high flow outfalls can be up to 50 fps, and may be higher depending on site-specific conditions.
- Eddies or back-rollers in the outfall pool and plume are minimized.
- The high flow outfall does not cause the cumulative total dissolved gas concentration released by the project to exceed accepted criteria.
- Adult fish that happen to encounter the outfall discharge are not prevented from continuing to move upstream, and those that may leap at the discharge should not strike any solid objects.

Johnson et al. (2003) published field studies and laboratory experiments to determine the relationship between direct injury and mortality rates of juvenile salmon (*Oncorhyncus spp*.) and jet entry velocities characteristic of high flow (> 28.3 m^3/s) outfalls at hydroelectric facilities. During field tests, the range of calculated mean entry velocities was 9.3-13.7 m/s for low (28.3 m^3/s) and high (68.0-70.2 m^3/s) outfall discharge rates and two receiving water elevations. Mortality and injury rates of balloon-tagged hatchery spring Chinook salmon juveniles in the field tests were less than 1%. At a high-velocity flume in a laboratory, small (87-100 mm fork length) and large (135-150 mm) hatchery fall Chinook salmon were exposed to velocities of 0.0-24.4 m/s in a fast-fish-to-slow-water scenario (Figure 3.34). Jet entry velocities up to 15.2 m/s provided benign passage conditions for the sizes and physiological states of juvenile salmonids tested under the particular environmental conditions present during this study. The authors concluded that direct injury and mortality results indicated that a jet entry velocity up to 15.2 m/s should safely pass juvenile salmon at high-flow outfalls. The authors concluded it will be necessary, however, to conduct site-specific, post-construction verification studies of fish injury and mortality at new high-flow outfalls.

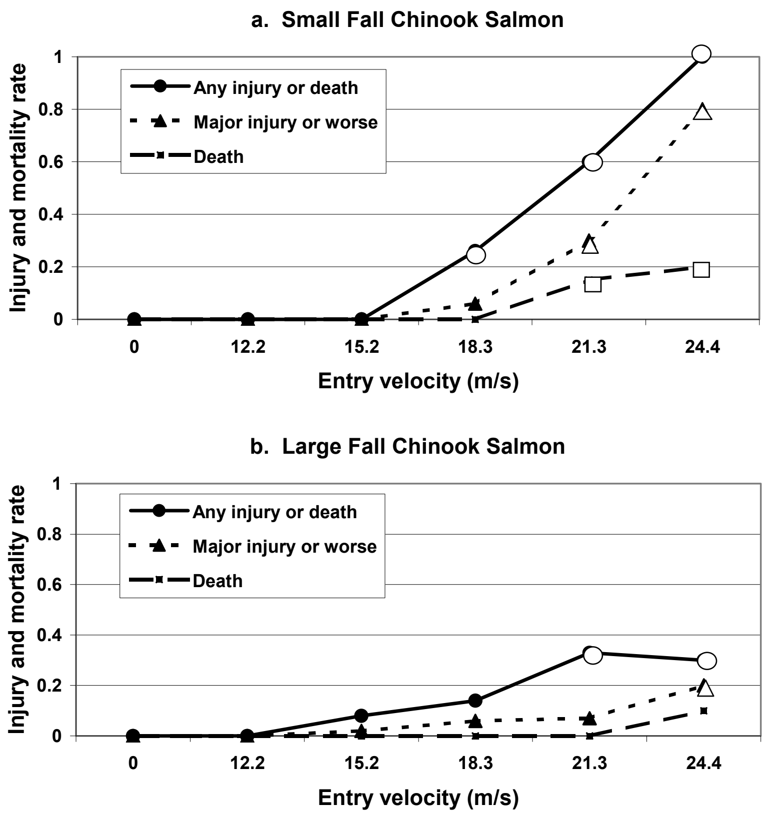

Figure 3.34. Injury and Mortality Rates from Experiments Conducted in a High-velocity Jet in a Laboratory Flume.

3.3.4.7 B2CC Design

The design effort for the B2 corner collector involved an outfall site and type selection study (INCA et al. 2001), as well as entrance gate, ogee, and conveyance channel design (USACE 2003). The overall system is depicted in Figure 3.35.

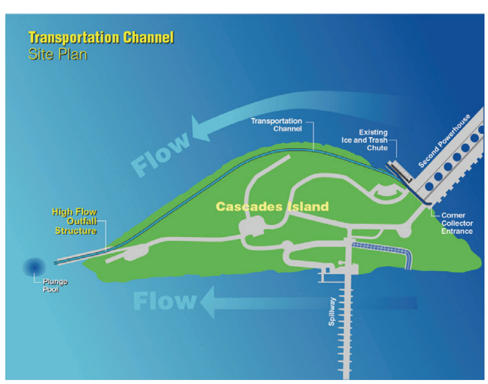

Figure 3.35. Plan View of the B2 Corner Collector Showing the Entrance (Far Right), Transportation Channel, and Outfall (Far Left). The figure was provided by CENWP.

The original entrance gate was replaced by a new gate and hoists. The usable entrance depth was increased from El. 62 to El. 52 ft. This increased discharge from about 2,200 to 5,200 cfs. Downstream of the entrance gate weir, an ogee was installed to smooth the passage route for juvenile salmonids and the conveyance channel was re-routed toward the new outfall location. The outfall was designed to accommodate a tailwater elevation range of El. 7-35 ft.

Design tools included physical-scale models (General 1:100, B2 Forebay 1:40, Outfall 1:30) and computational fluid dynamics (CFD) modeling. Figure 3.36 (photo courtesy of ENSR) shows a dye plume in the 1:30 scale physical model of the B2 corner collector outfall. Note the plunging flow and well-defined plume.

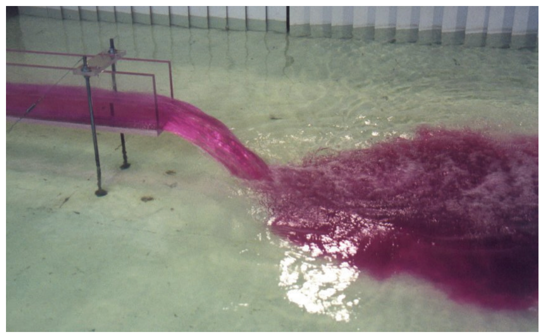

Figure 3.36. B2CC Outfall in 1:30 Model

The outfall type selection study (INCA et al. 2001) winnowed 13 original alternatives (Figure 3.37) down to one. This process involved setting criteria (e.g., cost, complexity, plume proximity to shorelines), rating the alternatives by multiple reviewers, and averaging the scores.

The final selection for the type of outfall, the mid-level cantilever, is shown in Figure 3.38. The conveyance structure is built at grade along the north shore of Cascades Island. The outfall is at a monolith at the downstream tip of the island. The invert is at El. 16 ft. It has a plunge pool 445 ft x 165 ft that was excavated to 50 ft below the existing bottom.

Site selection for the B2CC outfall started with nine alternatives (Figure 3.39). Egress conditions as shown in the 1:100 general model of Bonneville Dam were examined for each alternative. The final site selected was site "F" at the tip of cascades Island (Figure 3.39). INCA et al. (2001) documented the site selection process for the B2CC outfall.

3.3.4.8 Post-Construction Evaluation of the B2 Corner Collector: 2004-2005

Route-specific survival estimates for the B2CC were nearly 100%. In 2004 and 2005, Counihan et al. (2006a and 2006b) reported very high survival for yearling Chinook salmon (0.990-1.028 in 2004 and 1.02 in 2005), steelhead (1.02 to 1.03 in 2004 and 1.01 in 2005), and subyearling Chinook salmon (mean = 0.97 and range = 0.95 to 1.01 in 2004 and 1.01 in 2005).

These results are reported in greater detail with other project-wide and route-specific survival data in Sections 3.2.4 and 3.2.5. They are presented here to show that the new B2CC surface flow outlet is safe for juvenile salmonids and has the highest survival of all passage routes at Bonneville Dam.

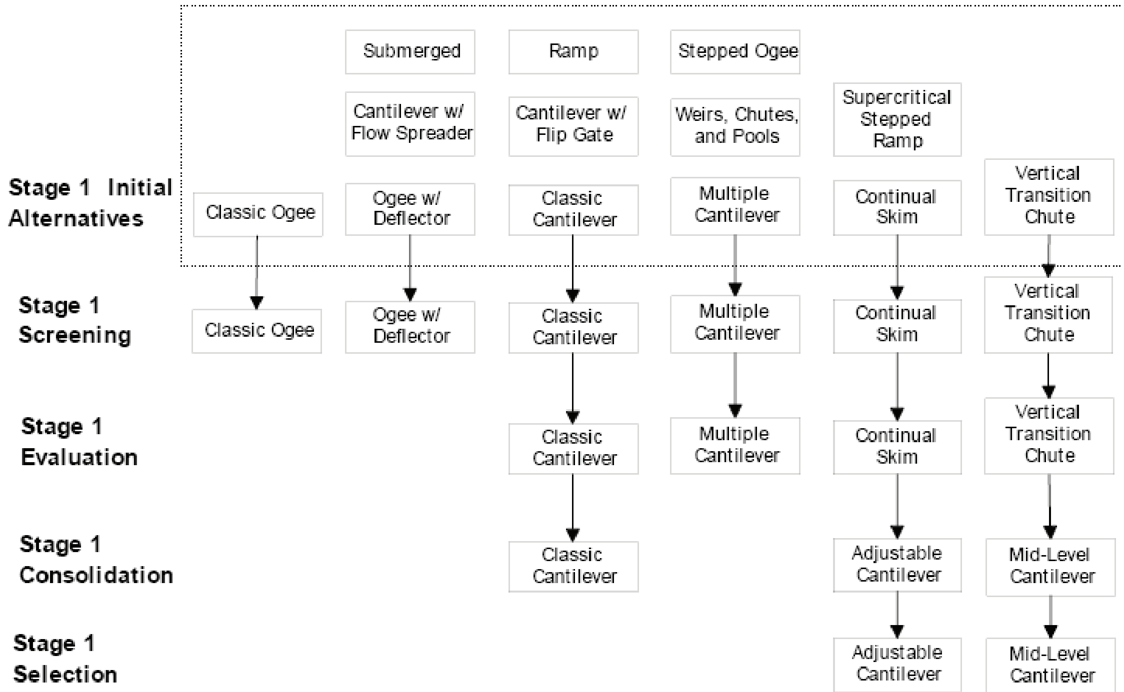

Figure 3.37. Process to Select the Outfall Type. Stage 1 was when the 13 original alternatives were narrowed down to two. The final selection was made in a subsequent stage.

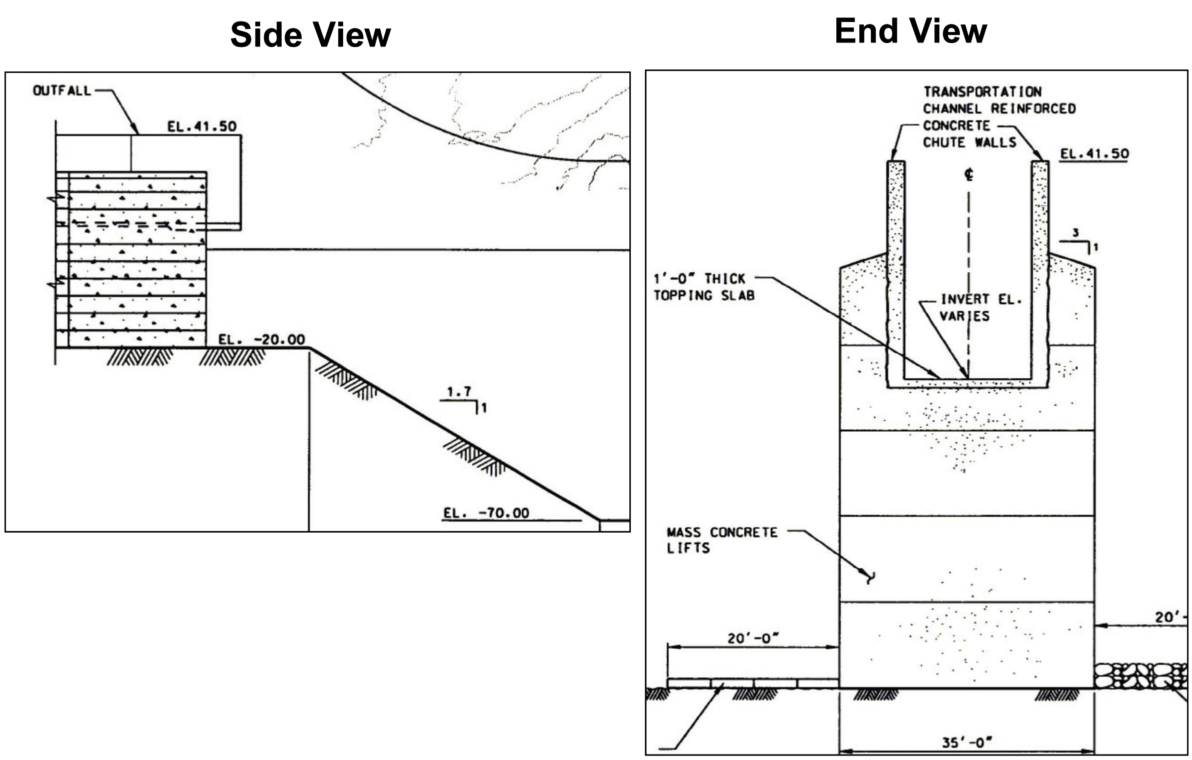

Figure 3.38. Schematic of the B2 Corner Collector Outfall: Mid-level Cantilever.

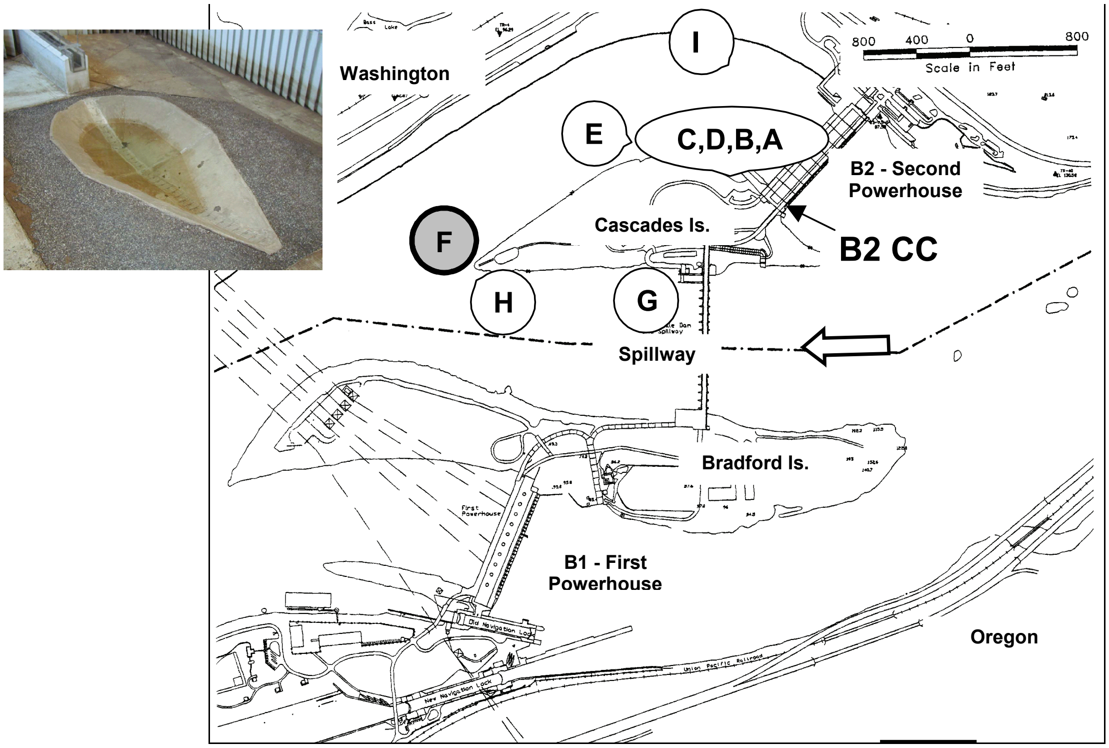

Figure 3.39. Map of Bonneville Dam Showing the Various Alternatives Studied during the B2CC Outfall Site Selection Process. Site F was chosen. The inset shows the 1:30 scale physical model of the outfall and its plunge pool.

Collection efficiency and effectiveness relative to B2 was highest for steelhead trout (66%-74%) and reasonably similar for the run-at-large (31%-32% in spring and 40%-44% in summer as estimated by hydroacoustic sampling to the estimate for Chinook salmon by radio telemetry (30%-37% in spring and 37-40% in summer) (Tables 3.2 through 3.5). For spring 2004 and 2005, fish-collection effectiveness relative to B2 averaged 7.3 for the run-at-large in spring, 6.5 for yearling Chinook salmon, and 13.7 for steelhead. In summer of those years, B2CC effectiveness relative to B2 was 7.3 according to the hydroacoustic estimate and 6.5 for subyearling Chinook salmon, according to the radio telemetry estimate (Tables 3.2 through 3.5).

3.3.4.9 B2 Corner Collector Conclusions

The B2 Corner Collector is a permanent, long-term surface flow outlet at the B2 powerhouse. It has a state-of-the-art conveyance channel and outfall that passes juvenile salmonids with utmost safety into environs downstream of the dam. The B2CC takes advantage of the location of the old sluice chute relative to the forebay eddy to pass surface-oriented emigrants. The intention is for the B2CC not to be a stand-alone route, but rather to complement the intake screen system to protect fish at B2. The efficiency and effectiveness was much higher for steelhead than it was for Chinook salmon for unknown reasons. Ways to improve the efficiency for juvenile Chinook salmon should be researched.

3.4 Fish Guidance Efficiency of Screens

3.4.1 Introduction

Intake screens intercept and guide into a juvenile bypass system a portion of the smolts entering turbines. The proportion of smolts entering the intake that is diverted is referred to as fish guidance efficiency (FGE). Two general types of screens are in place or have been tested at Bonneville Dam, submersible traveling screens (STS) and extended length submerged bar screens (ESBS). As of the writing of this report, no screens are in place at B1. They were removed prior to the 2004 migration given concerns over low survival associated with the bypass system.

Smolt FGE has been estimated using a variety of methods including simultaneous netting of intakes and gatewells, hydroacoustic sampling with fixed transducers, radio telemetry detections, and detection of PIT-tagged fish. At Bonneville Dam, estimates have been obtained using the first three approaches.

Estimates of FGE are highly variable and can be affected by numerous factors. These include the sampling method, screen type (STS or ESBS), time of day, operating conditions, species, and fish behavior/physiological changes during the migratory period (Ferguson et al. 2005). For these reasons, it is difficult to determine what the “real” or “effective” FGE is at a dam for a particular species, although often such estimates are requested by fishery managers. For example, passage models often require absolute measures of FGE as input parameters. More often, FGE is monitored at a dam to assess the change in diversion screen performance under different operating conditions and structural configurations. In this type of application, relative changes in FGE rather than absolute values are instructive and appropriate.

3.4.2 Fyke Net Studies

3.4.2.1 Bonneville First Powerhouse (B1)

The diversion screen evaluation and development program at B1 began in 1981. Krcma et al. (1982) and DeHart (1987) estimated that FGE exceeded 70% during the early spring test period. Later tests that year were compromised by a heavy debris load. DeHart (1987) reported that descaling attributable to the STS was negligible for all species examined except for sockeye. Approximately 7% of the guided sockeye were descaled, whereas only 3% of a non-screened control group was descaled. These encouraging results led to the installation of STS in all ten turbine units by the time of the 1983 migration.

Fish guidance efficiency was revisited again in 1988 at B1 following the construction of the new navigation lock and other actions in the forebay. Evaluations targeted subyearling Chinook salmon during late spring and summer periods. During the first week of June, the weighted mean FGE equaled 40.7% (Gessel et al. 1989), far below the 71.5% reported by Krcma et al. (1982) for the same sampling period. Even more disappointing was the very low mean FGE of 11.4% FGE documented during the summer sampling period (Table 3.14).

Evaluations in 1989 confirmed the poor results observed in 1988. The FGE for yearling Chinook salmon averaged 41.7 % (Table 3.14). Subyearling Chinook salmon FGE during the summer was even lower than measured the previous year, at 4.4 %. These continuing discouraging results prompted investigators to recommend detailed hydraulic studies and a systematic program to address guidance issues at B1.

Table 3.14. Estimates of FGE for Bonneville Dam Powerhouse 1. For fyke-net based estimates, we primarily report values for the control or reference screen configuration. These represent the general screen type in the majority of turbine units. This provides an FGE index that could be applied to the overall powerhouse. For other tools the specified screen configuration in some cases was not the standard reference configuration.

Year	Species or Season	FGE (Percent) Mean	FGE (Percent) Range	Range Screen Configuration	Evaluation Method	Source
1981	Y. Chin.	76.4	---	STS; Standard Elev.; 47 degree angle (pooled); (30 Apr. to 13 May) Unit 4	Fyke net	Krcma et al. (1982)
1989	Y. Chin.	41.7	(34.7 to 49.6)	STS; Standard Elev. (8 May to 14 May); Unit 3B	Fyke net	Gessel et al. (1990)
1991	Y. Chin.	45.8	(36.9 to 65.3)	STS; Standard Elev. (22 to 27 April); Unit 3B	Fyke net	Monk et al. (1992)
1991	Y. Chin.	31.7	(19.3 to 49.5)	STS; Standard Elev. (22 to 27 April); Unit 8B	Fyke net	Monk et al. (1992)
1991	Y. Chin.	28.9	(21.2 to 38.9)	STS; Standard Elev. (29 April to 4 May); Unit 5B	Fyke net	Monk et al. (1992)
1991	Y. Chin.	38.7	(34.7 to 45.0)	STS; Standard Elev. (29 April to 4 May); Unit 8B	Fyke net	Monk et al. (1992)
1991	Y. Chin.	46.5	(36.4 to 56.6)	STS; Standard Elev. (20 to 24 May); Unit 3B	Fyke net	Monk et al. (1992)
1991	Y. Chin.	45.4	(33.6 to 54.9)	STS; Standard Elev. (20 to 24 May); Unit 8B	Fyke net	Monk et al. (1992)
1992	Y. Chin.	46.0		STS; Standard Elev. (25 April to 20 May); Unit 3B	Fyke net	Monk et al. (1993)
1992	Y. Chin.	38.0		STS; Standard Elev. (25 April to 1 June); Unit 3B	Fyke net	Monk et al. (1993)
1998	Y. Chin.	72.0	(53 to 87)	ESBS; Unit 8B; 24 April to 21 May; No STS tests conducted this year	Fyke net	Monk et al. (1999b)
2000	Y. Chin.	66.0	(52 to 76)	ESBS; Unit 8B; 24 April to 24 May; No STS tests conducted this year	Fyke net	Monk and Sandford (2001)
2000	Y. Chin.	50.0	---	Spring Evaluation; All operable units; n = 153/305	Radio-Telemetry	Evans et al. (2001b)
2001	Y. Chin.	45.0	---	Spring Evaluation; All operable units; n = 5/11	Radio-Telemetry	Evans et al. (2001d)
2002	Y. Chin.	50.0	(32 to 58)[1]	Spring Evaluation; All operable units; n = 47/94	Radio-Telemetry	Evans et al. (2003a; 2006a)
1981	Sub. Chin.	71.5	---	STS; Standard Elev.; 47 degree angle (pooled); (30 Apr. to 13 May) Unit 4	Fyke net	Krcma et al. (1982)
1988	Sub. Chin.	40.7	(32.9 to 60.5)	STS; Standard Elev. (30 May to 6 June); Unit 3B	Fyke net	Gessel et al. (1989)
1988	Sub. Chin.	11.4	(5.5 to 28.1)	STS; Standard Elev. (6 July to 27 July); Unit 3B	Fyke net	Gessel et al. (1989)
1989	Sub. Chin.	36.8	(31.0 to 50.0)	STS; Standard Elev. (27 May to 30 May); Unit 3B	Fyke net	Gessel et al. (1990)
1989	Sub. Chin.	4.4	---	STS; Standard Elev. (12 July to 24 July); Unit 3B	Fyke net	Gessel et al. (1990)
1991	Sub. Chin.	32.9	---	STS; Standard Elev. (22 April to 24 May); Units 3B, 5B and 8B Combined	Fyke net	Monk et al. (1992)
1992	Sub. Chin.	22.0	---	STS; Standard Elev. (17 May to 1 June); Unit 3B	Fyke net	Monk et al. (1993)
1998	Sub. Chin.	67.0	---	ESBS; Unit 8B; 24 April to 21 May; No STS tests conducted this year	Fyke net	Monk et al. (1999b)
1998	Sub. Chin.	27.0	---	ESBS; Unit 8B; 29 June to 17 July; No STS tests conducted this year	Fyke net	Monk et al. (1999b)
2000	Sub. Chin.	46.0	(25 to 62)	ESBS; Unit 8B; 12 June to 7 July; No STS tests conducted this year	Fyke net	Monk and Sandford (2001)
2000	Sub. Chin.	29.0	---	Summer Evaluation; All operable units; n = 20/70	Radio-Telemetry	Evans et al. (2001a)
2001	Sub. Chin.	57.0	---	Summer Evaluation; All operable units; n = 4/7	Radio-Telemetry	Evans et al. (2001c)
2002	Sub. Chin.	43.0	(38 to 57)	Summer Evaluation; All operable units; n = 78/181	Radio-Telemetry	Evans et al. (2006b)
1981	Steelhead	77.0	---	STS; Standard Elev.; 47 degree angle (pooled); (30 Apr. to 13 May) Unit 4	Fyke net	Krcma et al. (1982)
1989	Steelhead	55.8	---	STS; Standard Elev. (9 to 14 May; and 27 to 30 May); Unit 3B	Fyke net	Gessel et al. (1990)
1991	Steelhead	59.1	---	STS; Standard Elev. (22 April to 24 May); Units 3B, 5B and 8B Combined	Fyke net	Monk et al. (1992)
1992	Steelhead	54.0	---	STS; Standard Elev. (29 April to 1 June); Unit 3B	Fyke net	Monk et al. (1993)
1998	Steelhead	85.0	---	ESBS; Unit 8B; 24 April to 21 May; No STS tests conducted this year	Fyke net	Monk et al. (1999b)
2000	Steelhead	76.0	---	ESBS; Unit 8B; 24 April to 24 May; No STS tests conducted this year	Fyke net	Monk and Sandford (2001)
2000	Steelhead	59.0	---	Spring Evaluation; All operable units; n = 131/223	Radio-Telemetry	Evans et al. (2001b)
2002	Steelhead	75.0	(67 to 100)[1]	Spring Evaluation; All operable units; n = 9/12	Radio-Telemetry	Evans et al. (2003a; 2006a)
1981	Coho	81.3	---	STS; Standard Elev.; 47 degree angle (pooled); (30 Apr. to 13 May) Unit 4	Fyke net	Krcma et al. (1982)
1988	Coho	56.8	---	STS; Standard Elev. (1 June); Unit 3B	Fyke net	Gessel et al. (1989)
1989	Coho	63.0	---	STS; Standard Elev. (9 to 14 May; and 27 to 30 May); Unit 3B	Fyke net	Gessel et al. (1990)
1991	Coho	58.2	---	STS; Standard Elev. (22 April to 24 May); Units 3B, 5B and 8B Combined	Fyke net	Monk et al. (1992)
1992	Coho	52.0	---	STS; Standard Elev. (29 April to 1 June); Unit 3B	Fyke net	Monk et al. (1993)
1998	Coho	80.0	---	ESBS; Unit 8B; 24 April to 21 May; No STS tests conducted this year	Fyke net	Monk et al. (1999b)
2000	Coho	76.0	---	ESBS; Unit 8B; 24 April to 24 May; No STS tests conducted this year	Fyke net	Monk and Sandford (2001)
1981	Sockeye	81.7	---	STS; Standard Elev.; 47 degree angle (pooled); (30 Apr. to 13 May) Unit 4	Fyke net	Krcma et al. (1982)
1991	Sockeye	27.4	---	STS; Standard Elev. (22 April to 24 May); Units 3B, 5B and 8B Combined	Fyke net	Monk et al. (1992)
1992	Sockeye	18.0	---	STS; Standard Elev. (25 April to 1 June); Unit 3B	Fyke net	Monk et al. (1993)
1998	Sockeye	51.0	---	ESBS; Unit 8B; 24 April to 21 May; No STS tests conducted this year	Fyke net	Monk et al. (1999b)
1996	Spring	49.0	---	(26 Apr to 24 May); Unit 3; outfitted with an STS	Hydroacoustics	Ploskey et al. (1998)
1996	Spring	29.0	---	(26 Apr to 24 May); Unit 5; outfitted with an STS	Hydroacoustics	Ploskey et al. (1998)
1998	Spring	79.0	---	Unit 1 B; outfitted with an STS	Hydroacoustics	Ploskey et al. (2001)
1998	Spring	46.0	---	Unit 2B; outfitted with an STS	Hydroacoustics	Ploskey et al. (2001)
2000	Spring	48.0	---	STS; Units 7, 9 and 10	Hydroacoustics	Ploskey et al. (2002a)
2001	Spring	47.0	(0.22 to 0.57)	(1 May to 9 June); Units 1-10 (Unit 8 w/ESBS, no U3)	Hydroacoustics	Ploskey et al. (2002b)
2002	Spring	---	(0.21 to 0.79)	(20 April to 2 June); Units 1-10 (Unit 8 w/ESBS, no U5)	Hydroacoustics	Ploskey et al. (2003)
1996	Summer	57.0	---	Summer Evaluation (14 June to 12 July); Unit 3; outfitted with an STS	Hydroacoustics	Ploskey et al. (1998)
1996	Summer	49.0	---	Summer Evaluation (14 June to 12 July); Unit 5; outfitted with an STS	Hydroacoustics	Ploskey et al. (1998)
1998	Summer	62.0	---	Summer Evaluation; Unit 1B; outfitted with an STS	Hydroacoustics	Ploskey et al. (2001)
1998	Summer	21.0	---	Summer Evaluation; Unit 2B; outfitted with an STS	Hydroacoustics	Ploskey et al. (2001)
2000	Summer	36.0	---	Summer Evaluation; STS; Units 7, 9 and 11	Hydroacoustics	Ploskey et al. (2002a)
2001	Summer	47.0	(0.29 to 0.53)	Summer Evaluation (1 to 15 July); Units 1-10 (Unit 8 w/ESBS, no U3)	Hydroacoustics	Ploskey et al. (2002b)
2002	Summer	---	(0.20 to 0.79)	(3 June to 15 July); Units 1-10 (Unit 8 w/ESBS, no U5)	Hydroacoustics	Ploskey et al. (2003)

[1] Range over varying spill operations, taken from Table 9 of Evans et al. (2006b)

By 1998, the focus shifted to evaluating ESBS and different operating gate configurations. FGE improved markedly during the spring with an ESBS in place. Summer estimates of FGE were also considerably higher than previously documented with the STS as shown in Table 3.15 (from Monk et al. 1999b). The FGE gains in the spring were substantial with the ESBS, but summer improvements were disappointing to many managers. Later in this report we note that hydroacoustic indices for summer migrants also indicate low FGE. By the spring of 2004, guidance screens had been removed from Powerhouse 1. Thus, no FGE estimates exist after 2003.

Table 3.15. Mean FGE Estimates for the ESBS (1998) and the STS (1988, 1989, and 1991) by Species from Monk et al. (1999b). Standard errors shown in parentheses.

Species	ESBS (1998)	STS (1988, 1989 and 1991)
Yearling Chinook	72 (1.9)	36 (2.4)
Steelhead	85 (1.5)	58 (3.5)
Coho	80 (2.3)	53 (4.9)
Sockeye	51 (5.0)	25 (3.1)
Subyearling Chinook	---	---
Spring sampling	67 (4.7)	33 (4.0)
Summer sampling	23-48 (1.1-2.7)	4-11 (1.0-2.0)

3.4.2.2 Bonneville Second Powerhouse (B2)

In 1982, with the completion of B2, the downstream migrant bypass system was activated. In 1983, initial FGE evaluations were conducted. During that era fish passage managers had established a generic FGE goal of 70% for all species. Krcma et al. (1984), using the fyke net method, reported values that generally ranged from 20%-40%, far below the stated standard. For the next two decades, numerous operations and configurations were tested as a means to improve FGE with minimal injury to fish.

The conditions tested often consisted of combinations of assorted actions including raised operating gates, lowered STS, blocked trashracks, lights, reconfigured trashracks, flow turning vanes, turbine intake extensions, etc. Gessel et al. (1991) summarized results obtained from 1983-1989. Performance was improved for spring migrants with FGE attaining levels near 70%. The actions that resulted in the highest FGE included lowering the STS by 22 inches, streamlining the trashracks, and installing TIEs. However, FGE for summer migratory ocean-type Chinook salmon remained substandard at below 30% (Table 3.16).

Based on those early preliminary findings, TIEs were installed across the face of the powerhouse, but fish guidance performance was disappointing. Monk et al. (1999a) noted that FGE tests conducted in 1993 and 1994 with STS in place revealed that guidance of spring migrants had dropped to about 50%. This was considerably lower than the 70% observed in the late 1980s and well below the new regional standard of 80% FGE. Furthermore, results were highly variable and thus there was difficulty identifying the combination of conditions and structures that resulted in poor FGE.

Table 3.16. Estimates of FGE at the Bonneville Dam Powerhouse 2. For fyke-net-based estimates, we primarily report values for the control or reference screen configuration. These represent the general screen-type in the majority of turbine units at the powerhouse. This provides an FGE index that could be applied to the overall powerhouse. For other tools, the specified screen configuration in some cases was not the standard reference configuration.

Year	Species or Season	FGE Percent Mean	FGE Percent Range	Screen Configuration	Evaluation Method	Source
1983	Y. Chin.	19.3	(6.3 to 50.6)	STS; Standard Depth; Angles of 47 and 60 Degrees (Pooled)	Fyke net	Krcma et al. (1984)
1984	Y. Chin.	32.0	---	STS; Standard Depth; Angle of 60 Degrees; with trash rack deflector; Unit 12; 2-3 June	Fyke net	Gessel et al. (1985)
1985	Y. Chin.	33.4	---	STS; Standard Depth; Angle of 65 Degrees; streamlined trash rack; Unit 12B; 3-7 May	Fyke net	Gessel et al. (1986)
1986	Y. Chin.	44.3	---	STS; 27" lowered Depth; Angle of 55 Degrees; streamlined trash rack; Unit 12B; 21-29	Fyke net	Gessel et al. (1987)
1986	Y. Chin.	35.2	---	STS; 27" lowered Depth; Angle of 55 Degrees; standard trash rack; Unit 12A; 23-29	Fyke net	Gessel et al. (1987)
1986	Y. Chin.	60.5	---	STS; 27" lowered Depth; Angle of 55 Degrees; streamlined trash rack; Unit 12B; 19-24	Fyke net	Gessel et al. (1987)
2000	Y. Chin.	39.0	---	Spring Evaluation; All operable units; n = 156/398	Radio-Telemetry	Evans et al. (2001b)
2001	Y. Chin.	46.0	---	Spring Evaluation; All operable units; n = 417/915	Radio-Telemetry	Evans et al. (2001d)
2002	Y. Chin.	37.0	(30 to 45)[1]	Spring Evaluation; All operable units; n = 251/674	Radio-Telemetry	Evans et al. (2003a; 2006a)
2004	Y. Chin.	33.0	(31 to 37)	Spring Evaluation; All operable units; n = 730/2,229	Radio-Telemetry	Reagan et al. (2006)
2005	Y. Chin.	36.0	(29 to 42)	Spring Evaluation; All operable units; n = 786/2,160	Radio-Telemetry	Adams et al. (2006)
1983	Sub. Chin.	24.3	(7.4 to 55.3)	STS; Standard Depth; Angles of 47 and 60 Degrees (Pooled); Day and Night (Pooled)	Fyke net	Krcma et al. (1984)
1984	Sub. Chin.	22.0	---	STS; Standard Depth; Angle of 60 Degrees; with trash rack deflector; Unit 12; 2-3 June	Fyke net	Gessel et al. (1985)
1984	Sub. Chin.	27.0	---	STS; Standard Depth; Angle of 60 Degrees; no trash rack deflector; Unit 12; 17-22 July	Fyke net	Gessel et al. (1985)
1985	Sub. Chin.	9.9	---	STS; Standard Depth; Angle of 65 Degrees; standard trash rack; Unit 12A; 16-19 July	Fyke net	Gessel et al. (1986)
1985	Sub. Chin.	13.6	---	STS; Standard Depth; Angle of 65 Degrees; streamlined trash rack; Unit 12B; 20-23 July	Fyke net	Gessel et al. (1986)
1987	Sub. Chin.	---	(2 to 34)	STS's in unit 12; summer run of subyearling chinook; 14 to 31 July	Fyke net	Gessel et al. (1988)
2000	Sub. Chin.	25.0	---	Summer Evaluation; All operable units; n = 1/4	Radio-Telemetry	Evans et al. (2001a)
2001	Sub. Chin.	35.0	---	Summer Evaluation; All operable units; n = 169/479	Radio-Telemetry	Evans et al. (2001c)
2002	Sub. Chin.	47.0	(36 to 59)	Summer Evaluation; All operable units; n = 317/681	Radio-Telemetry	Evans et al. (2006b)
2004	Sub. Chin.	22.0	(20 to 24)	Summer Evaluation; All operable units; n = 714/312	Radio-Telemetry	Evans et al. (2006c)
2005	Sub. Chin.	24.0	(15 to 42)	Summer Evaluation; All operable units; n = 367/1,572	Radio-Telemetry	Adams et al. (2006)
1983	Steelhead	34.7	(15.3 to 50.0)	STS; Standard Depth; Angles of 47 and 60 Degrees (Pooled)	Fyke net	Krcma et al. (1984)
2000	Steelhead	55.0	---	Spring Evaluation; All operable units; n = 90/163	Radio-Telemetry	Evans et al. (2001b)
2002	Steelhead	59.0	(50 to 63)[1]	Spring Evaluation; All operable units; n = 135/229	Radio-Telemetry	Evans et al. (2003a; 2006a)
2004	Steelhead	40.0	(40 to 44)	Spring Evaluation; All operable units; n = 273/685	Radio-Telemetry	Reagan et al. (2006)
2005	Steelhead	36.0	(34 to 40)	Spring Evaluation; All operable units; n = 258/711	Radio-Telemetry	Adams et al. (2006)
1983	Coho	24.7	(25.6 to 35.0)	STS; Standard Depth; Angles of 47 and 60 Degrees (Pooled)	Fyke net	Krcma et al. (1984)
1983	Sockeye	14.0	(0.0 to 28.6)	STS; Standard Depth; Angles of 47 and 60 Degrees (Pooled)	Fyke net	Krcma et al. (1984)
1987	Spring	32.0	---	STS; 30" lowered Depth; Angle of 55 Degrees; streamlined trash rack; Unit 12B; 21 Apr.	Hydroacoustics	Magne (1987a,c)
1987	Spring	---	(25 to 75)	STS's in unit 12; mix of Y. chinook and coho; 21 Apr. to 3 June	Fyke net	Gessel et al. (1988)
1996	Spring	37.0	(16.0 to 66.0)	Spring Evaluation; Units 11A, 12A, 13C, 14B, 15B, 16C, 17B, and 18A	Hydroacoustics	Ploskey et al. (1998)
1997	Spring	4.2	(0.0 to 7.44)	Spring Evaluation; Unit 11A; STS with TIE; sluice gate closed	Hydroacoustics	BioSonics (1998)
1997	Spring	2.4	(0.0 to 8.34)	Spring Evaluation; Unit 11A; STS with TIE; sluice gate operated at 61'	Hydroacoustics	BioSonics (1998)
1997	Spring	5.0	(2.75 to 8.24)	Spring Evaluation; Unit 11A; STS with TIE; sluice gate closed	Hydroacoustics	BioSonics (1998)
1997	Spring	2.5	(1.08 to 4.78)	Spring Evaluation; Unit 11A; STS with TIE; sluice gate operated at 68'	Hydroacoustics	BioSonics (1998)
1998	Spring	55.0	---	Spring Evaluation; Units 11-13; No TIE's in Units 11-14; Sluice Gate not operated	Hydroacoustics	Ploskey et al. (2001a)
2000	Spring	52.0	---	Spring Evaluation; Units 11-18; Sluice Gate Operational	Hydroacoustics	Ploskey et al. (2002a)
2001	Spring	56.0	(0.35 to 0.72)	Spring Evaluation (1 May to 9 June); Units 11-18 (Unit 15 modified); Sluice Gate	Hydroacoustics	Ploskey et al. (2002b)
2002	Spring	53.0	---	(20 April to 2 June); Units 11-18 (Units 15 and 17 modified)	Hydroacoustics	Ploskey et al. (2006)
2004	Spring	48.0	± 3.33	Spring Evaluation with Corner Collector operating	Hydroacoustics	Ploskey et al. (2005)
2005	Spring	45.0	± 4.33	Spring Evaluation with Corner Collector operating	Hydroacoustics	Ploskey et al. (2006c)
1996	Summer	26.0	(10.0 to 42.0)	Summer Evaluation; Units 11A, 12A, 13C, 14B, 15B, 16C, 17B, and 18A	Hydroacoustics	Ploskey et al. (1998)
1997	Summer	2.8	(1.02 to	Summer Evaluation; Unit 11A; STS with TIE; sluice gate closed	Hydroacoustics	BioSonics (1998)
1997	Summer	2.2	(0.38 to 8.55)	Summer Evaluation; Unit 11A; STS with TIE; sluice gate operated at 68'	Hydroacoustics	BioSonics (1998)
1998	Summer	30.0	---	Summer Evaluation; Units 11-13; No TIE's in Units 11-14; Sluice Gate not operated	Hydroacoustics	Ploskey et al. (2001a)
2000	Summer	38.0	---	Summer Evaluation; Units 11, 13, 14, 15, 16, 17, 18; Sluice Gate Operational	Hydroacoustics	Ploskey et al. (2002a)
2001	Summer	44.0	(0.11 to 0.54)	Summer Evaluation (1 July to 15 July); Units 11-18 (Unit 15 modified); Sluice Gate	Hydroacoustics	Ploskey et al. (2002b)
2002	Summer	---	(0.25 to 0.65)	(3 June to 15 July); Units 11-18 (Units 15 and 17 modified)	Hydroacoustics	Ploskey et al. (2003)
2004	Summer	36.0	± 2.93	Summer Evaluation with Corner Collector operating	Hydroacoustics	Ploskey et al. (2005)
2005	Summer	37.0	± 4.43	Summer Evaluation with Corner Collector operating	Hydroacoustics	Ploskey et al. (2006c)
1988	All	---	---	---	Fyke net	Gessel et al. (1989)
1989	All	---	---	---	Fyke net	Gessel et al. (1990)
1993	All	---	---	---	Fyke net	Monk et al. (1994)
1994	All	---	---	---	Fyke net	Monk et al. (1995)
2001	All	---	---	---	Fyke net	Monk et al. (2002)

[1] Range over varying spill operations, taken from Table 9 of Evans et al. (2006b)

[2] Range over varying spill operations, taken from Table 9 of Evans et al. (2006b)

[3] 95% Confidence Limit

In their review of information gathered through 1998, NOAA Fisheries investigators identified factors that could be contributing to the poor FGE at B2 (Monk et al. 1999a). The two most important ones were as follows:

- A hydraulic bottleneck exists above the STS screens that may be restricting the flow of water and fish into the gatewell and bypass.
- Unique hydraulic conditions in the forebay cause large-scale current patterns along the face of the dam that affect the vertical distribution of smolts upon entering turbine intakes.

Using that information as a foundation, the fishery agencies directed the USACE to initiate a thorough FGE improvement study for B2 that included ample hydraulic modeling and a full assessment of biological benefits and risks. To accomplish this, the USACE contracted with INCA Engineers et al. (1999) who assembled a team of hydraulic, structural, and civil engineers and fish passage biologists to conduct the study. Based on results and recommendations from that study and those previously reported by Monk et al. (1999a), several cost-effective and promising actions were implemented and evaluated in 2001. These included

- removal of a section of concrete beam to accommodate a larger VBS and improve hydraulic conditions
- installing a turning vane above the STS to improve hydraulic conditions
- Installing a gap closure at the upper downstream edge of the STS to direct more flow and fish upward into the gatewell.

Monk et al. (2002) evaluated the combined biological effect of these conditions and structural modifications. FGE increased dramatically over that last documented in 1994 with the standard STS configuration, i.e., all species exhibited a net improvement in FGE. In the modified unit, FGE during spring testing averaged 71%, 82%, 88%, and 62% for yearling Chinook salmon, steelhead, coho, and subyearling Chinook salmon, respectively. During the summer, FGE for subyearling Chinook salmon was the highest observed before at either powerhouse, at 57%. Furthermore, screen-related injury and descaling rates were among the lowest observed since the Second Powerhouse has been operated.

3.4.2.3 Characterizing FGE at B1 and B2: Fyke-Net Data

Fishery managers and analysts require estimates of FGE to apply in certain evaluations, such as those involving fish passage models. FGE estimates are just one of many input parameters that are used to populate a passage model. Selecting a representative value for the species of interest can be challenging as witnessed by the variability in measured values and ever-changing screen systems. The difficulty is magnified if retrospective analyses are pursued, which requires establishing what effective FGE was at some point in history. Often such details are ignored or cannot be reasonably determined. In most cases a generic value that is considered representative is applied across dam configuration eras. This can result in rather coarse assessments.

The most recent generic FGE values for B1 and B2 were reported by Ferguson et al. (2005) (see Table 3.17).

Table 3.17. Generic FGE Values for B1 and B2 Calculated by NOAA Staff for the 1999 Dam Configuration Compared with Those Used Last in the PATH Modeling Forum.

	PATH		**NOAA – 1999 Configuration**	
Species	B1	B2	B1	B2
Yearling Chinook	41	43	38	44
Subyearling Chinook	---	---	16	18
Steelhead	---	---	41	48

These values were distilled from the complex of fyke net-based FGE estimates in the historical database. Staff used their judgment in selecting values that they believed were most representative of the general dam configuration pre-BiOp. Some of those estimates were then adjusted based on side-by-side PIT tag and fyke net data obtained at Snake River dams to yield the values above. Later in this report we will compare these FGE indices with those obtained using other tools.

3.4.3 Hydroacoustics

Hydroacoustic sampling methods were used to estimate FGE at Bonneville Dam in the late 1980s. Magne (1984 and 1987a,b,c), and Magne et al. (1986 and 1989), and Stansell et al. (1990) used hydroacoustics to monitor smolt passage through select units and found positive correlations with FGE estimates based on fyke net sampling. Thorne and Kuehl 1989 evaluated the efficacy of using hydroacoustic techniques for estimating FGE at B1 in 1988. In the late 1990s, as research efforts focused increasingly on evaluating diversion screen performance, more complex and extensive use of hydroacoustics for estimating FGE became common place.

In 1996, Ploskey et al. (1998) observed that FGE at B2 varied among seasons, time of day, and turbine units monitored. FGE was higher during spring than summer and higher during day than night sampling periods. They also reported that the 1996 hydroacoustic estimates were of similar magnitude to previously reported estimates from fyke net sampling. The mean difference in ten estimates was 10.7%, with a 95% CI of 5%.

In 1997, some incongruous estimates of FGE were reported by BioSonics (1998). Across a variety of test configurations in Unit 11a, spring FGE ranged from only 2.4% to 5.0% (Table 3.16). Estimates obtained during the summer were even lower, ranging from 2.2% to 2.8%. Operation of the sluice chute adjacent to the unit had no appreciable affect on FGE. It was very low regardless of whether the chute was operating. The estimates reported by BioSonics are about an order of magnitude lower than those documented in any other FGE evaluation at this site, regardless of the tool employed. We conclude these estimates are an anomaly and are not useful for representing FGE dynamics at B2.

In 1998, sampling was done at select units at B1 (Ploskey et al. 2001a). As observed with other techniques, FGE was lower during the summer than in the spring (Table 3.14). But the persistent sampling also revealed that there was a continual declining trend in FGE throughout the summer sampling period. This was consistent with patterns observed with both hydroacoustics and net sampling (Figure 3.40). That same year at B2, they observed that FGE also decreased throughout the summer.

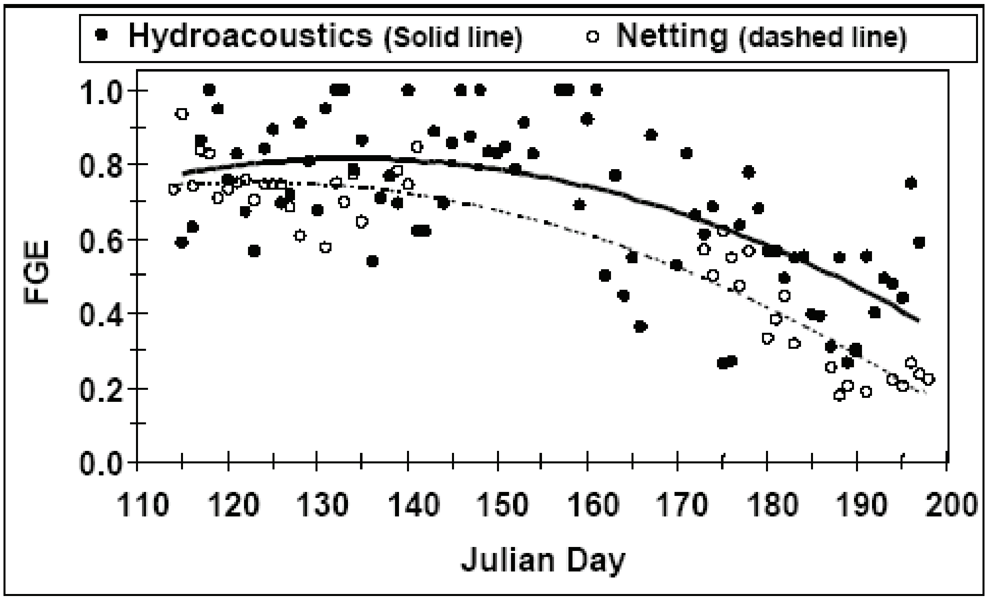

Figure 3.40. FGE of an Extended-length Bar Screen at Intake 8b Estimated by Fixed Aspect Hydroacoustics and Netting. Netting data were collected and provided by the NMFS. From Ploskey et al. 2001a, Figure 25; data from 1998.

In 2000, an ESBS was installed in Unit 8 at B1 and FGE was monitored (Ploskey et al. 2002a). They found that the ESBS FGE was greater than STS FGE. Also, they reported a strong correlation (r^2=0.65) between hydroacoustic and fyke net-based FGE estimates obtained by NOAA investigators (Figure 3.28). Their extended monitoring revealed a dramatic temporal trend of decreasing FGE from spring through summer, regardless of screen type (Figure 3.28). As a point of contrast, we note later in this report that the PSC efficiency remained high throughout the entire spring and summer sampling periods. Over the sampling period, the average FGE was 46% during the spring and 36% in summer.

In 2001, following recommendations by ENSR and NMFS (Monk et al. 1999a), the USACE modified the VBS and intake structure at Unit 15 (B2). A broad multi-pronged evaluation of B1 and B2 was undertaken using hydroacoustics, net sampling, and radio-telemetry. With respect to FGE, the objective was to determine the effect of modifications to Unit 15 (Ploskey et al. 2002c). Also, other observations reinforced findings from previous years. They noted that spring FGE was greater than summer FGE, based on both hydroacoustic and fyke net sampling.

Hydroacoustic estimates of FGE were consistent with and similar to net-based estimates (Figure 3.41). FGE varied widely across turbine units (Figure 3.42). Importantly, FGE in the modified Unit 15 was consistently higher than unmodified units fitted with STS (Figure 3.43). Ploskey et al. (2002c) also reported that season-wide FGE estimates based on hydroacoustics and radio-telemetry varied by as much as 10% as illustrated in Table 3.18. The difference in estimates is not surprising, given the methods in which investigators using each tool document, monitor, and calculate FGE is fundamentally different.

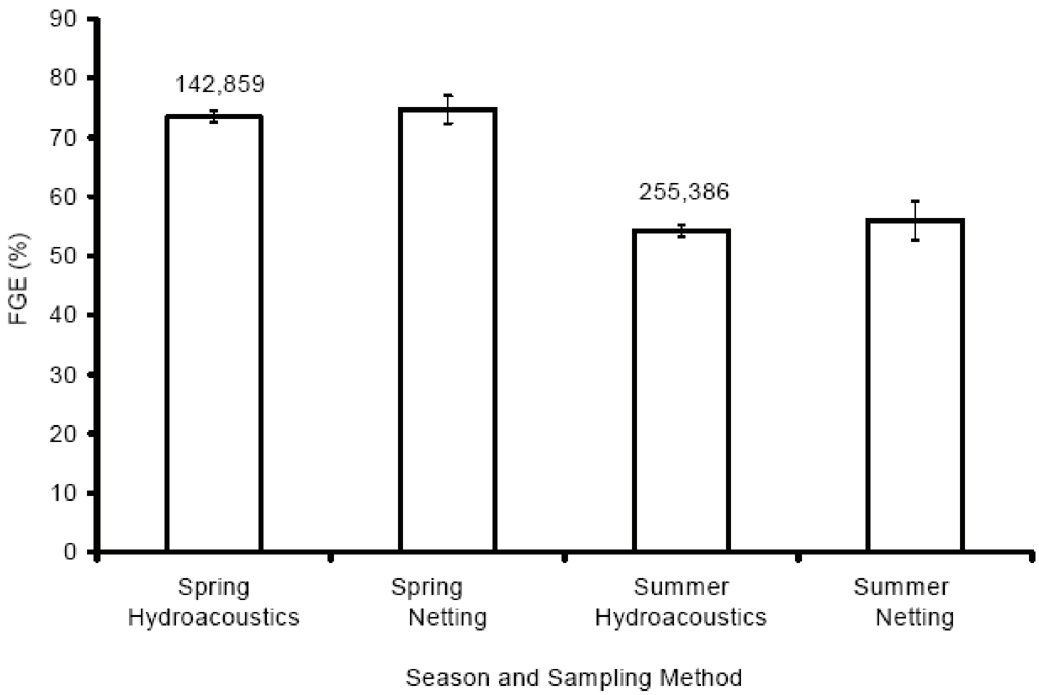

Figure 3.41. Plot of FGE Estimates Made from all Nighttime Hours of Hydroacoustic Sampling (2000-0500) Compared to Estimates based on Netting from about 2000 to 2100 or 2200 h. Vertical bars are 95% confidence limits. The expanded numbers of fish upon which FGE estimates were based are shown above the bars for hydroacoustic sampling each season. 2001 data, figure reproduced from Ploskey et al. (2002c, Figure S.2).

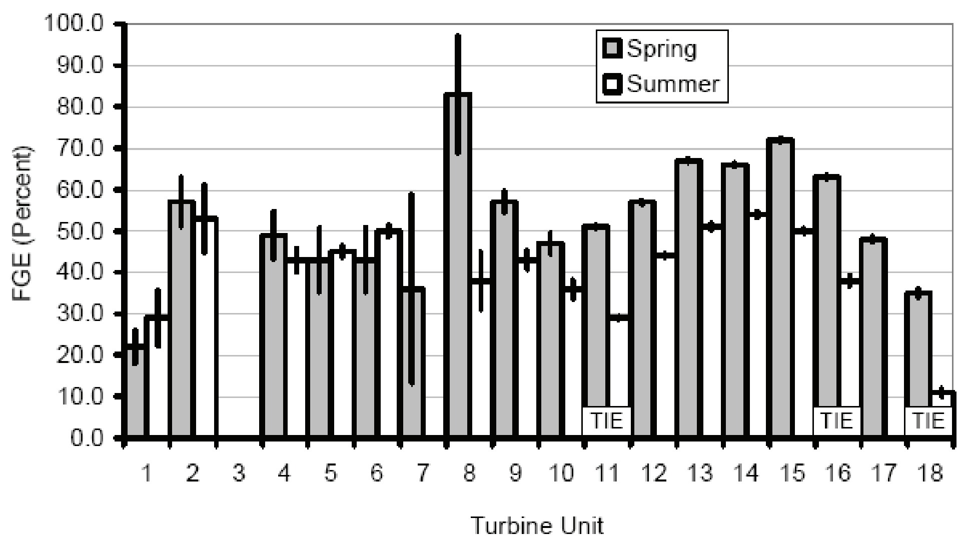

Figure 3.42. Estimates of FGE and 95% Confidence Limits for Turbine Units at Bonneville Dam in Spring and Summer. Figure reproduced from 2001 data (Ploskey et al. 2002c, Figure 3.43).

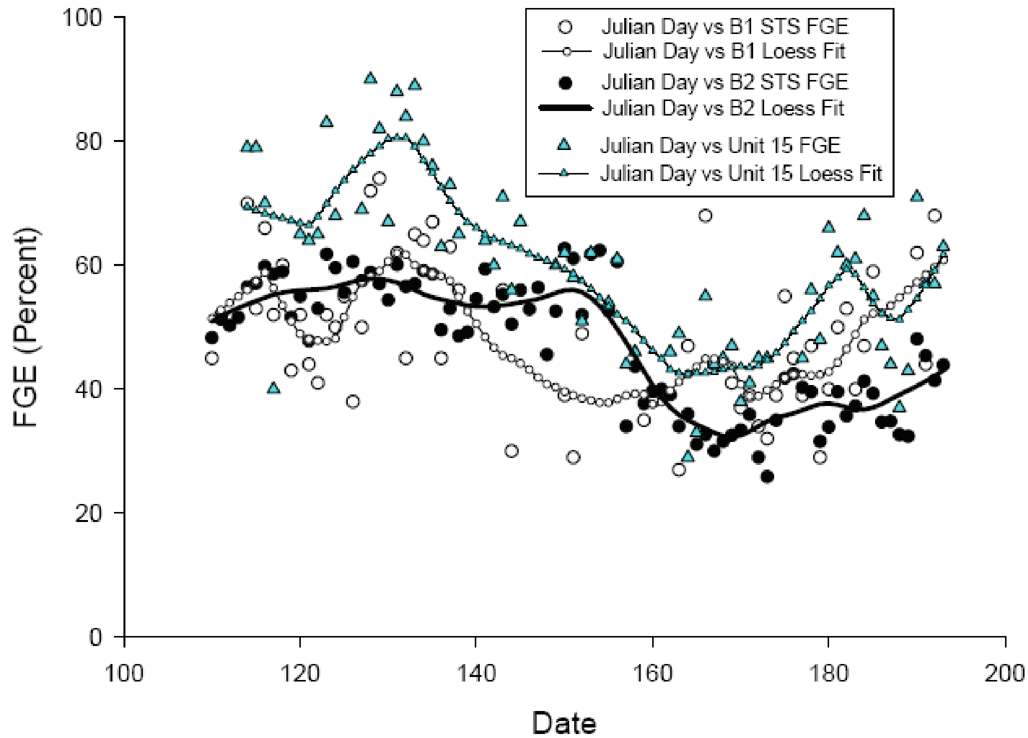

Figure 3.43. Comparison of FGE among Types of Units with STS at Powerhouse 1, Powerhouse 2, and at Modified Unit 15 by Date. 2001 data, figure reproduced from Ploskey et al. (2002c, Figure 3.42).

Table 3.18. Hydroacoustic and Radiotelemetry Estimates of FGE at B1 and B2 in 2001

Period/Powerhouse	Hydroacoustics	Radio-Telemetry
	Spring	
B1	47%	45%
B2	56%	46%
	Summer	
B1	47%	57%
B2	44%	35%

In 2002, Ploskey et al. (2003) noted that FGE was highest in units at B2 that had been modified (units 15 and 17), and at Unit 8 at B1, which was equipped with an ESBS (Figure 3.44). A seasonal decrease in FGE was still apparent at some units, even the modified Unit 17 (Figure 3.45). Furthermore, the presence or absence of TIEs did not appear to influence FGE as much as the location of the unit across B2 (Figure 3.45).

By the start of the 2004 out-migration, guidance screens had been removed from the First Powerhouse, and the corner collector was in full operation at B2. The effect of the corner collector on FGE at B2 was of interest. Ploskey et al. (2005 and 2006c) provided FGE estimates that suggested that FGE had dropped slightly from levels observed in previous years, at least during the spring (Table 3.2). The summer estimates suggest a similar effect compared to 2001 and 2002 but not relative to 2000 (Table 3.3). This could have been the result of the B2CC shallow fish that otherwise may have been guided by screens, as hypothesized by Adams et al. (2006).

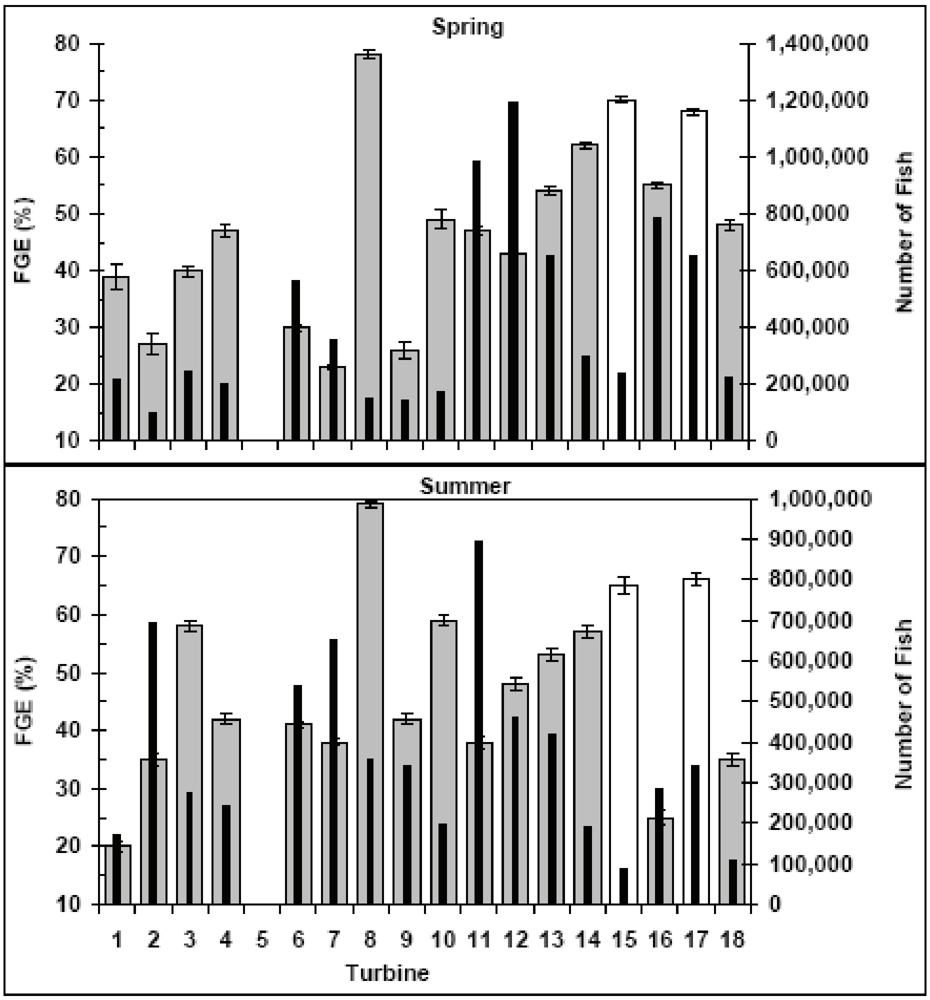

Figure 3.44. Comparison of FGE (Wide Bars) and Fish Passage (Narrow Black Bars) among Turbines at Bonneville Dam in Spring and Summer 2002. Turbines 1-10 are located at B1 and turbines 11-18 are at B2. All turbine intakes have submerged traveling screens except for intakes at Unit 8 (lined bar), which had extended submerged bar screens. The gatewells at units 15 and 17 (white bars) were modified to increase flow up the slot relative to gatewells at other units (11-14, 16, and 18) Error bars are 95% confidence limits. 2002 data, reproduced from Ploskey et al. (2003, Figure S.12).

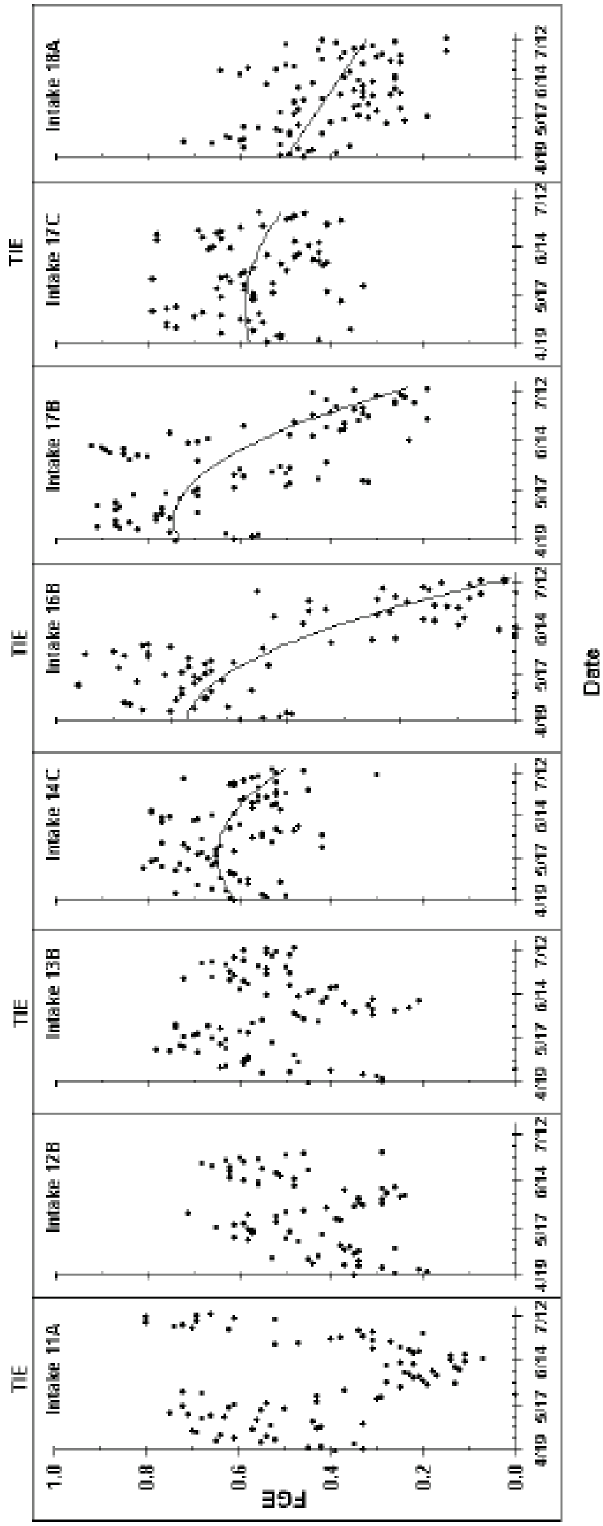

Figure 3.45. Plots of Seasonal Trends of Intake-Specific FGE for B2 in 2002 with Labels Indicating the Intakes that were Behind, as Opposed to, Between TIES. Intake 15B only ran during the spring and therefore was not plotted. 2002 data, reproduced from Ploskey et al. (2003, Figure 3.1.6).

3.4.4 Radio Telemetry Estimates

3.4.4.1 Bonneville Powerhouse 1

Beginning in 2000, radio-telemetry was used to estimate FGE as well as passage. In 2000, Evans et al. (2001a and 2001b) reported FGE estimates for three species (Table 3.14). FGE reflected the fraction of fish arriving at the powerhouse that were guided by the collective screens into the JBS. That year, the average FGE was 50% for yearling Chinook salmon, 59% for steelhead, and 29% for subyearling Chinook salmon during the summer.

In 2001, only estimates for yearling and subyearling Chinook salmon were reported (Evans et al. 2001c and 2001d). FGE averaged 45% and 57% for each species, respectively (Table 3.14). The value for subyearling Chinook salmon was surprisingly high; since estimates generated using other tools have consistently indicated much lower values. Furthermore, that summer estimate is nearly twice the level observed the previous year using telemetry. This estimate may well be unrealistic and may be an artifact of the low sample size of only seven fish detected at the powerhouse, with only four of those being identified as guided.

In 2002, overall FGE for yearling Chinook salmon was estimated at 50%, and 75% for steelhead (Figure 3.14; Evans et al. 2003a). The sample size for steelhead was notably low with 9 of 12 fish at the powerhouse being guided.

Although measures of precision were not reported by the authors, it was apparent that sample sizes varied considerably across years. Once Bonneville Powerhouse 2 became the priority powerhouse, sample sizes at Bonneville 1 dropped dramatically.

3.4.4.2 Bonneville Powerhouse 2

In 2000, FGE estimates at Bonneville 2 were generally similar to those reported at Bonneville 1, except for yearling Chinook salmon which was 11 percentage points lower at Bonneville 2 (Table 3.16). The FGE over the period radio-tagged fish were passing the dam was 39%, 55%, and 25% for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively. In 2001, FGE was 46% for yearling Chinook salmon and 35% for subyearling Chinook salmon. In 2002, FGE for yearling Chinook salmon and steelhead were lower than observed at Bonneville 1 the same year, averaging 37% and 59%, respectively. Adams et al. (2006) hypothesized that lower FGE at B2 in 2004 and 2005 was due to the corner collector passing the majority of the shallow fish, fish that may otherwise have been guided.

In general, the radio-tag estimates of FGE appear to be sound species-specific indices, as long as a satisfactory number of fish arrive at the powerhouse and enter the screened bypass system. With Bonneville 2 as the priority unit and increased spill levels realized in recent years, it will be increasingly difficult to obtain ample recoveries at Bonneville 1 to provide robust FGE estimates at that powerhouse.

3.4.5 Comparison Among Tools

Attempts to compare absolute values of FGE that were obtained using different tools are not particularly instructive. Methods not only differ in sampling capability, but also differ with respect to the population they monitor or index. Thus, it is not surprising that different tools yield different estimates. To illustrate such differences, we present hydroacoustic and radio-telemetry estimates obtained in two recent years (Table 3.19).

Table 3.19. Season-Wide FGE Estimates for each Entire Powerhouse as Determined Using Radio Telemetry and Hydroacoustics. Standard Errors are indicated as such, other precision estimates are at 95% confidence limits.

Estimate	B2 – 2004	B2 – 2005
Radio-telemetry – Yearling Chinook	33% (S.E. = 1.0)	36% (S.E. = 1.0)
Radio-telemetry – Steelhead	40% (S.E. = 1.9)	36% (S.E. = 1.8)
Hydroacoustics – Spring	48% (± 3.3)	45% (± 4.3)
Radio-telemetry – Subyearling Chinook	22% (S.E. = 0.7)	24% (S.E. = 1.1)
Hydroacoustics – Summer	36% (± 2.9)	37% (± 4.4)

We focus on B2 FGE, because these data are most relevant given contemporary operations (B2 priority and corner collector operations). Consistently, hydroacoustic estimates are greater than those obtained with radio-telemetry (Table 3.19). This pattern was evident during spring and summer sampling periods in both 2004 and 2005.

Both sets of estimates apply to each entire powerhouse over the range of operating conditions prevailing in those years. The difference in the values yielded by different tools is obvious, but bears repeating. Each telemetry-based estimate is specific to that species, whereas hydroacoustic estimates reflect the population at large. In the spring, the population is comprised of more species than merely yearling Chinook salmon and steelhead. Coho are also abundant in the spring at Bonneville Dam. The proportions of the different species will affect the FGE estimate using hydroacoustics. In the summer, the presence of shad also contributes to the FGE estimate at times, so that summer estimates do not always pertain exclusively to salmonids. Also, there are late-migrating steelhead and yearling Chinook salmon that can contribute to the summer hydroacoustic estimate.

The fyke net-based estimates common in early years, are based on measurements taken in primarily a single unit that differed across years and sampling was brief, spanning only a few hours in any one season. These limited estimates were, in turn, extrapolated across all turbines. We regard this approach to be a rather coarse index of the effective FGE for any powerhouse and question its utility in characterizing the overall performance of screened bypass systems.

For years when there was full hydroacoustic coverage of the turbine units across a powerhouse, the season-wide estimates have the capacity to generally represent overall FGE at either powerhouse, albeit lacking species-specific indicators. In such years, the sampling technique is spatially and temporally extensive and able to capture the pronounced variability inherent in these dynamics.

In many cases the radio-telemetry estimates reflect FGE performance across the entire powerhouse and across seasonal operating conditions for individual species, providing perhaps the most useful overall species-specific index of FGE. However, sample sizes must be high enough to provide reliable estimates.

3.4.6 Synthesis and Conclusions

In viewing the collective FGE information obtained with fyke nets, hydroacoustics, and radio-telemetry, we submit the following synthesis and conclusions.

Establishing reliable, representative estimates of powerhouse FGE for use in retrospective passage modeling analyses for either B1 or B2 will be difficult. We could not readily identify any preferred set of estimates. Results vary by turbine unit, configuration, operations, and monitoring tool. There is no correct or best estimate of FGE available for application across all years. Furthermore, across and within years, so many conditions have been explored and tested that no typical or standard FGE can easily be distilled from the information. Managers seeking such estimates will have to make value judgments regarding the suitability of year-specific estimates for use in retrospective model analyses. NOAA, the Action Agencies, and state and tribal biologists engaged in such an effort as part of the 2006 remand process for the BiOp. Managers must determine what the further monitoring objectives are for Bonneville Dam and select the appropriate tool and method to satisfy them.

The fyke net method for estimating FGE seems best suited for evaluating different screen configurations in side-by-side comparisons. Since such evaluations involve only monitoring one or two units, this technique is not well suited for generating FGE estimates that represent performance across the entire powerhouse.

Hydroacoustic monitoring seems well suited for providing season-wide estimates of FGE if temporal and spatial coverage of the powerhouse is adequate. It is also the only practical method for documenting temporal changes in FGE over the migration period. An obvious shortcoming is the lack of species–specific information, but depending on the management objectives, this may not be a handicap.

The radio-telemetry method provides sound estimates of the effective FGE across the entire powerhouse during the period tagged fish are passing the project. This may be the most representative estimate of FGE that could be adopted and applied in model analyses. Even so, only a few estimates from recent years are available.

3.5 Fine-Scale Passage Distribution

3.5.1 Introduction

The distribution of downstream fish passage at Bonneville Dam reported over the last two decades has been derived from two sampling techniques: fixed-aspect hydroacoustics and radio telemetry. Each technique has important advantages and limitations. For example, fixed-aspect hydroacoustics detects enough fish at individual turbines, sluiceways, and spill bays to provide passage distribution data for the run at large but is limited by the inability to distinguish species of fish. Radio telemetry studies provide species-specific information for a few tagged species or age groups, but usually cannot provide robust passage distributions among individual turbines, spill bays, and sluiceways, although data usually are sufficient to describe passage distribution by type of route (e.g., B1 turbines, B1 sluiceway, spillway or type of spill bay with 7- or 14-ft elevation spill deflectors, B2 turbines, B2 JBS, and B2CC). This section of the report describes fish passage distributions using both techniques.

The use of hydroacoustics for assessing fish passage at Bonneville Dam began in 1985 with Nagy and Magne (1986) where fish distributions and fish guidance efficiency were first reported for two turbine units at B2. Turbine passage estimates for that initial hydroacoustic study, as well as for follow-on efforts in 1986 and 1987 (Magne et al. 1986; Magne 1987c) were likely inaccurate due to transducer deployment location. These early turbine passage studies using hydroacoustics at Bonneville Dam were based on assessing fish distributions with transducers deployed on the upstream face of the trashracks and aimed upward into the forebay. Targets ensonified by beams upstream of the trashracks may not have been committed to passage and thus should not be considered accurate measures of passage distributions. For this reason, we decided not to include passage estimates from these early studies in this synthesis report. By 1997, transducer deployment evolved to placement on the downstream side of the trashracks, where detected fish are assumed to be committed to passage (Magne et al. 1989). Early hydroacoustic passage investigations typically focused on just two or three turbine units, whereas recent efforts have included coverage at all routes of passage through Bonneville Dam (e.g., Ploskey et al. 2003).

Fish passage distribution studies at Bonneville Dam using radio telemetry techniques date back to Holmberg et al. (1996). That effort resulted in the first estimates of species-specific fish passage by primary structure (B1, B2, or spillway). Since 1996, each successive year through the present, radio telemetry has been used to assess horizontal and diel fish passage distributions at Bonneville Dam.

3.5.2 Horizontal Distributions

3.5.2.1 Powerhouse 1

3.5.2.1.1 Hydroacoustics

Ploskey et al. (1998) reported horizontal distribution of fish targets across all intakes (A, B and C) of units 3 and 5 in spring of 1996, indicating fewer fish were passed via intakes 5B and 5C relative to the other four intakes (Figure 3.46). Reasons for the differences are unknown. Hydroacoustic estimates for fish passage into Sluiceway Outlet 5C were not correlated with estimates from an up-looking video camera, but the camera clearly detected more fish near the piers than near the middle of the outlet.

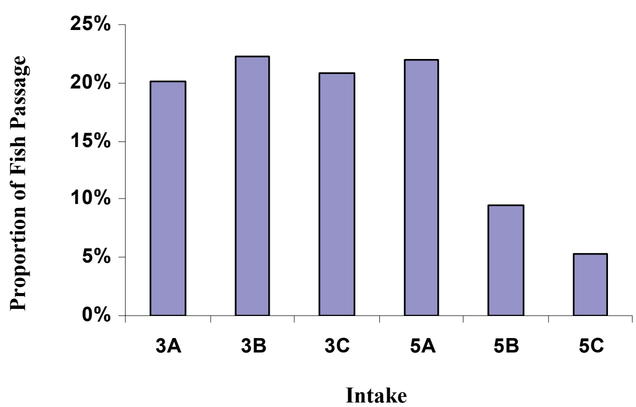

Figure 3.46. Relative Fish Passage at each Intake in Units 3 and 5 in 1996. Plot created from Ploskey et al. 1998.

In 1998, Ploskey et al. (2001b) evaluated a Prototype Surface Collector (PSC) designed to simulate entrance hydraulics associated with 5-ft and 20-ft slot widths at Powerhouse 1 in front of Intakes 3B and 5B. Hydroacoustic estimates of lateral fish distribution across the PSC intakes with the 20-ft slot indicated greater proportions of fish at the south and north portions of the intake compared to the middle of the intake during both spring and summer (Figure 3.47). This may have been indicative of fish tracking along the face of the PSC to discover an opening. Guided fish were those that passed into the collector slot and were detected inside the turbine above the floor elevation. Unguided fish were those detected below the collector.

Horizontal distribution of fish passage within and among intakes of Unit 5 in 1999 was not uniform based on data from the two pairs of transducers sampling in each intake (Figure 3.48; Ploskey et al. 2001b). A Wilcox sign rank test of the significance of the data indicated the most prevalent skew in distribution occurred at Intake 5C with unguided fish passage, where the south side showed significantly greater passage than the north side across slot treatment and season (Table 3.20). It also showed that guided fish passage was significantly greater through the north side of intakes A and C in spring and in all intakes in summer (Ploskey et al. 2001b).

Horizontal distribution of total fish passage at B1 turbines in 2000 indicates Units 4 and 9 had the highest fish passage during both the spring and summer (Figure 3.49; Ploskey et al. 2002a). Units 7, 8, and 10 passed the fewest fish for B1 in both seasons.

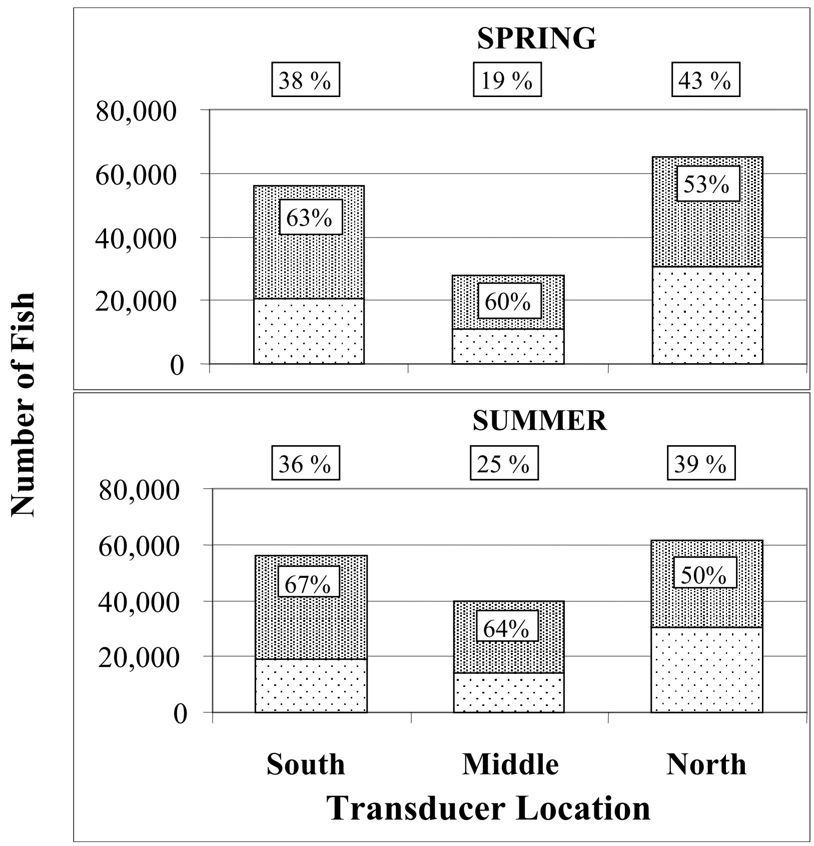

Figure 3.47. Lateral and Vertical Distribution of Fish Passing through 20-ft-wide Slots in the Prototype Surface Collector (PSC) at Intakes 3b and 5b in 1998. Percentages at the top of each graph indicate the lateral distribution of fish across the slot entrance. Shaded portion of bars and labels in the bars show the percent of PSC-collected fish that were counted in the upper half of the slot entrance to the PSC. Plot from Ploskey et al. 2001a.

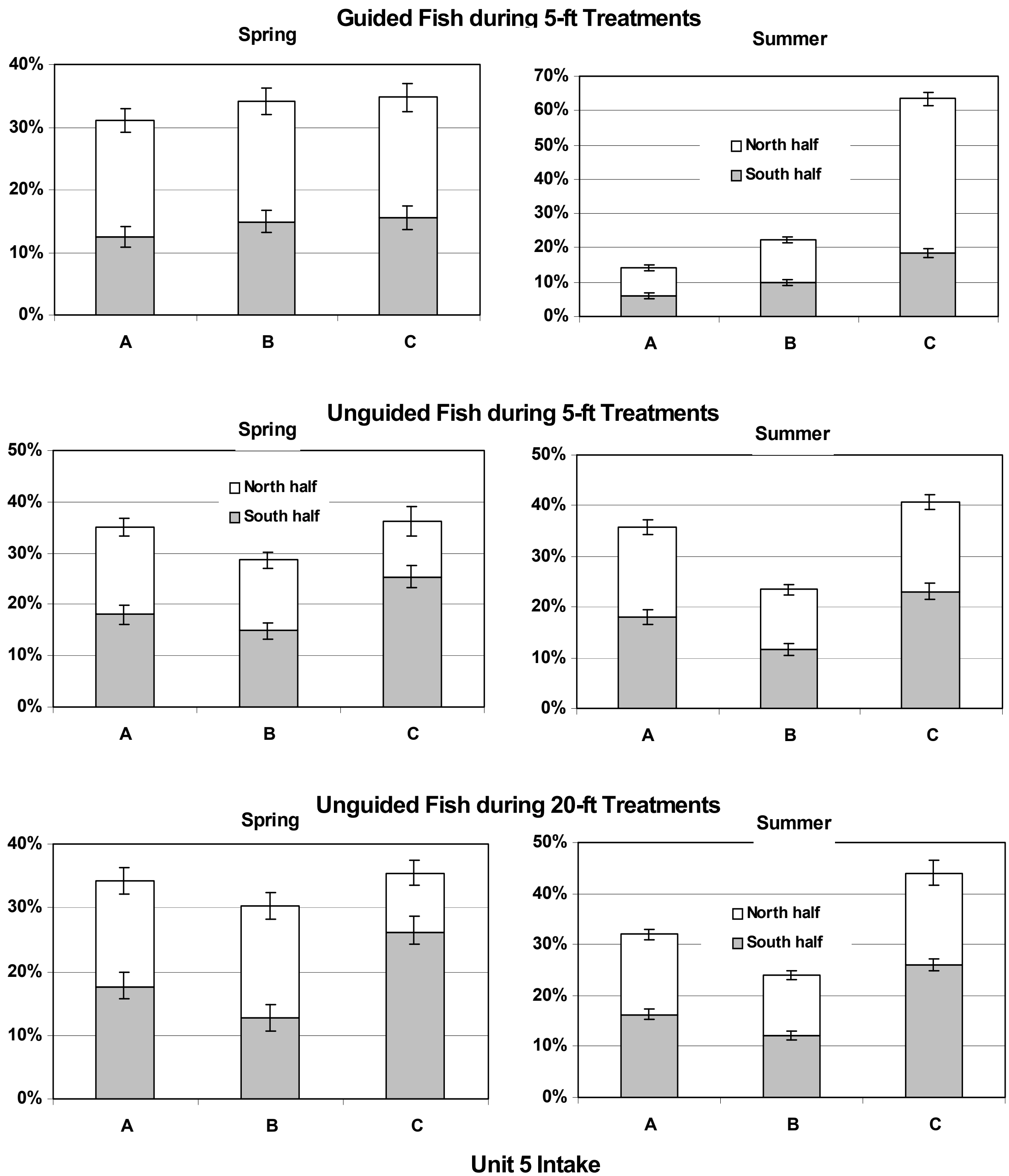

Figure 3.48. Percent of Fish Passage among and within Intakes of Unit 5 in Spring and Summer 1999. Guided fish during 5-ft treatments are shown in the upper plots, unguided fish are shown during 5-ft (middle plots) and 20-ft treatments (lower plots). Proportions of fish within intakes are illustrated with light (north half) and dark (south half) portions of bars. Error bars reflect 95% confidence limits. Figure from Ploskey et al. 2001b.

Table 3.20. Results from Wilcoxon Sign Rank Test. Tests compare guided and unguided fish passage estimates between locations within intakes of Unit 5 by slot treatment and season for 1999. Locations within intakes are labeled as n (north) and s (south). Significant differences are indicated by showing the nature of the relationship between intake locations. Numbers in parentheses indicate probability values (Pr=|S|). The sample size (N) reflects the number of test days per season. Table from Ploskey et al. 2001b.

		INTAKE A			INTAKE B			INTAKE C		
Season	Slot	N	Guided	Unguided	N	Guided	Unguided	N	Guided	Unguided
spring	5	18	n > s (0.002)	no diff	16	no diff	no diff	18	n > s (0.014)	s > n (0.0001)
spring	20	18	n / a	no diff	16	n / a	n > s (0.001)	18	n / a	s > n (0.0001)
summer	5	20	n > s (0.005)	no diff	20	n > s (0.004)	no diff	20	n > s (0.0001)	s > n (0.0001)
summer	20	20	n / a	no diff	20	n / a	no diff	20	n / a	s > n (0.0002)

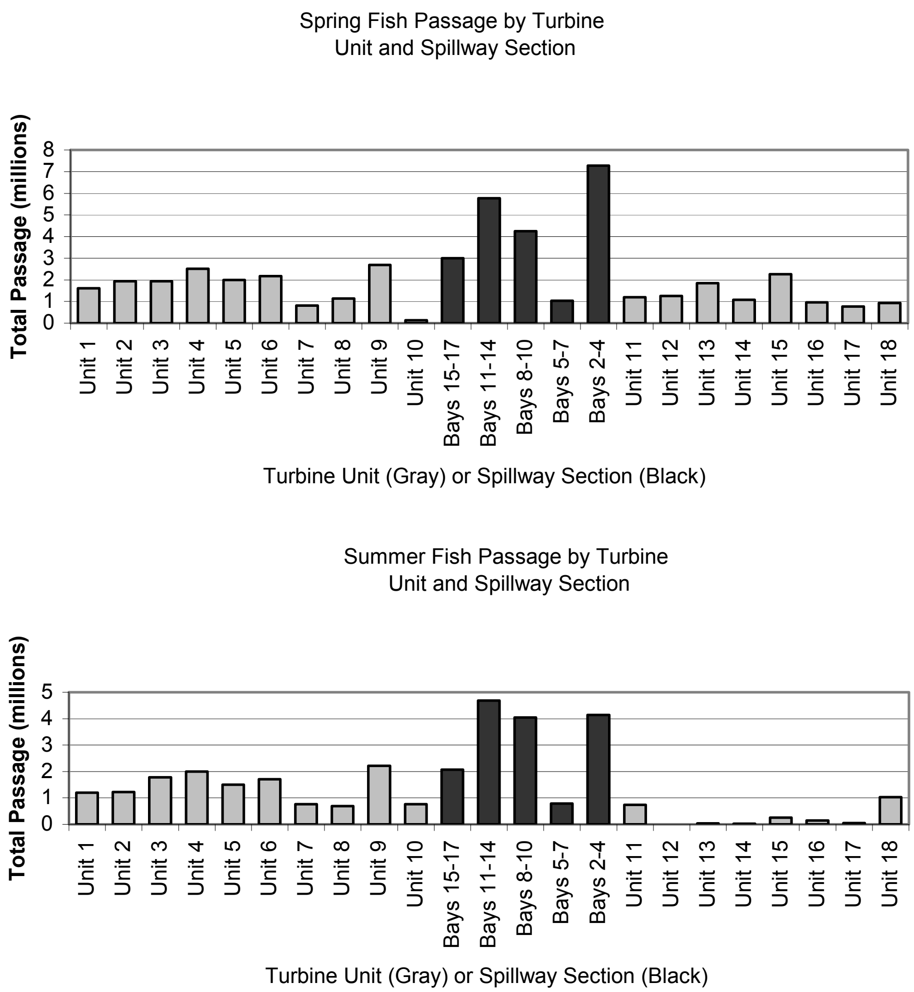

Figure 3.49. Horizontal Distribution of Total Fish Passage at B1 and B2 Turbines and the Spillway in Spring and Summer 2000. Figure from Ploskey et al. 2002a.

Year 2001 was considered a drought, and as such B1 represented only about 7% of total discharge through the project for both spring and summer since B2 was given priority for generation. Ploskey et al.

(2002c) sampled B1 turbine units and reported that, during the short duration the B1 units were operable, Units 9 and 10 passed the greatest number of fish in both spring and summer (Figure 3.50).

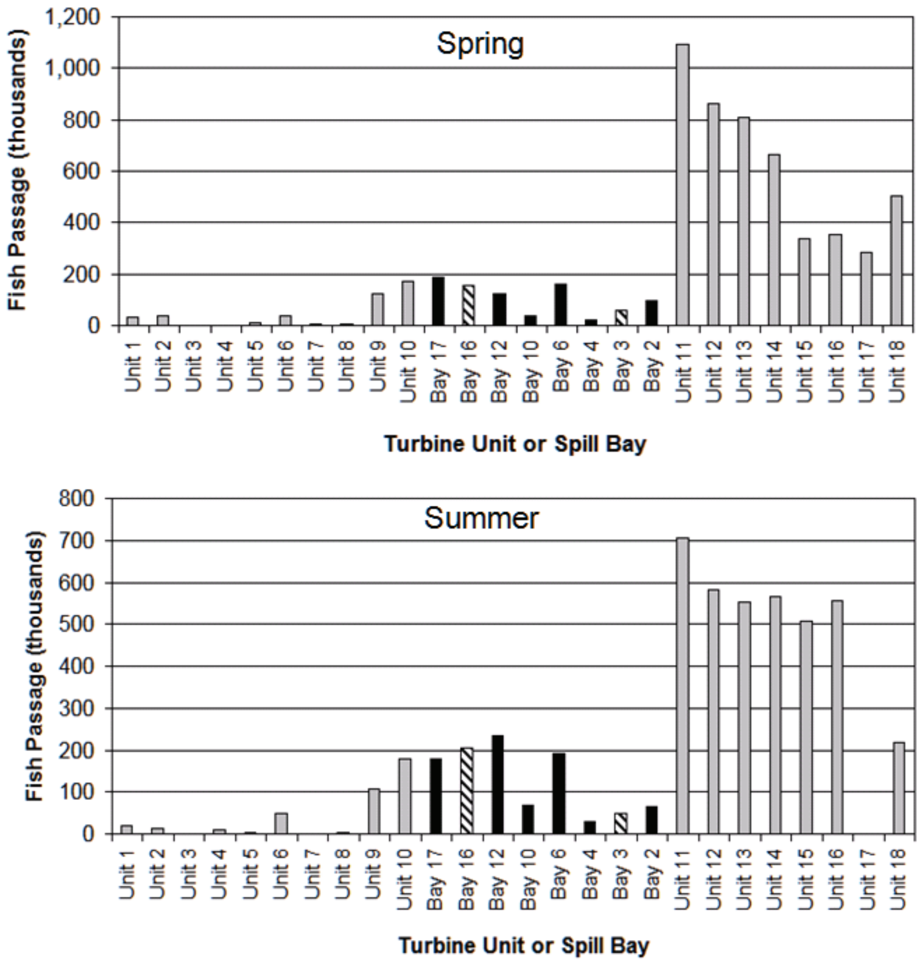

Figure 3.50. Horizontal Distribution of Fish Passage through Turbines (Gray Bars) and Spill Bays (Black or Striped Bars) in Spring (Top) and Summer (Bottom) 2001. Spill bays 1 and 18 were opened only four inches and other bays that were closed all season are not displayed. Estimates for spill bays 3 and 16 were interpolated from the nearest operating spill bays. Turbine unit 17 did not operate in summer. Figure from Ploskey et al. 2002c.

Horizontal distribution of fish passage at B1 in spring of 2002 revealed a general trend of higher passage through the central units (particularly units 6 and 7) and lower passage at units 2, 8, and 9 (Figure 3.51; Ploskey et al. 2003). The sluiceway at Intake 7B dominated passage, passing an estimated 33% of all fish at B1. In summer, units 2, 6, and 7 passed the most fish while units 1 and 10 passed the fewest. As in the spring, the sluiceway at B1 passed more fish than any individual turbine (about 30% of total passage at B1). Patterns of distribution of fish per water volume differed from patterns for total passage; in spring the highest densities passed through Unit 9 and the lowest passed through Unit 4 (Figure 3.52). Summertime passage densities peaked through units 1 and 6, with lowest densities through Unit 10. The sluiceway passed inordinately greater densities of fish relative to individual turbines in both spring and summer.

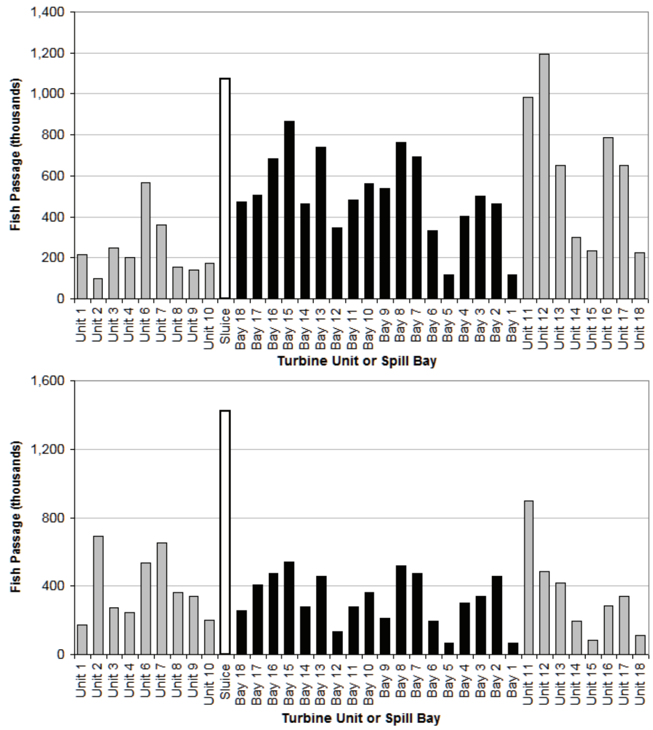

Figure 3.51. Horizontal Distribution of Fish Passage through Bonneville Dam in Spring (Top) and Summer (Bottom) 2002. Passage through turbines at B1 and B2 is shown with gray bars, through the B1 sluiceway by the white bar, and through the spill bays by black bars. Unit 5 was not operable in 2002. Figure from Ploskey et al. 2003.

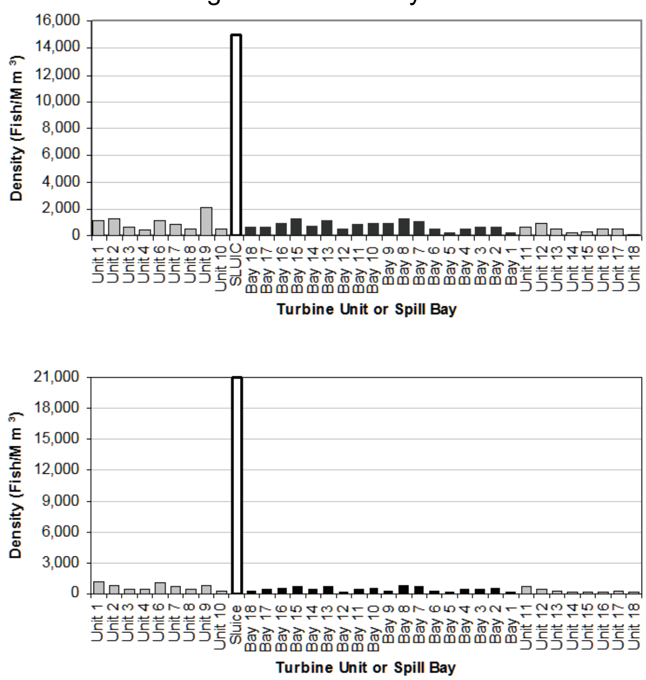

Figure 3.52. Horizontal Distribution of Fish Density through Bonneville Dam in Spring (Top) and Summer (Bottom). Fish density through turbines at B1 and B2 is shown with gray bars, through the B1 sluiceway by the white bar, and through the spill bays by black bars. Unit 5 was not operable in 2002. Figure from Ploskey et al. 2003.

In 2002, Ploskey et al. (2003) sampled fish passage into the sluiceway entrance at Intake 7A using both hydroacoustics and video techniques. The horizontal distribution of passage into the sluiceway was higher in the middle than near the sides and was slightly skewed toward the south in both spring and summer (Figure 3.53). The horizontal distributions estimated by both methods were similar, although the hydroacoustic sampling provided much finer resolution than did the four optical cameras.

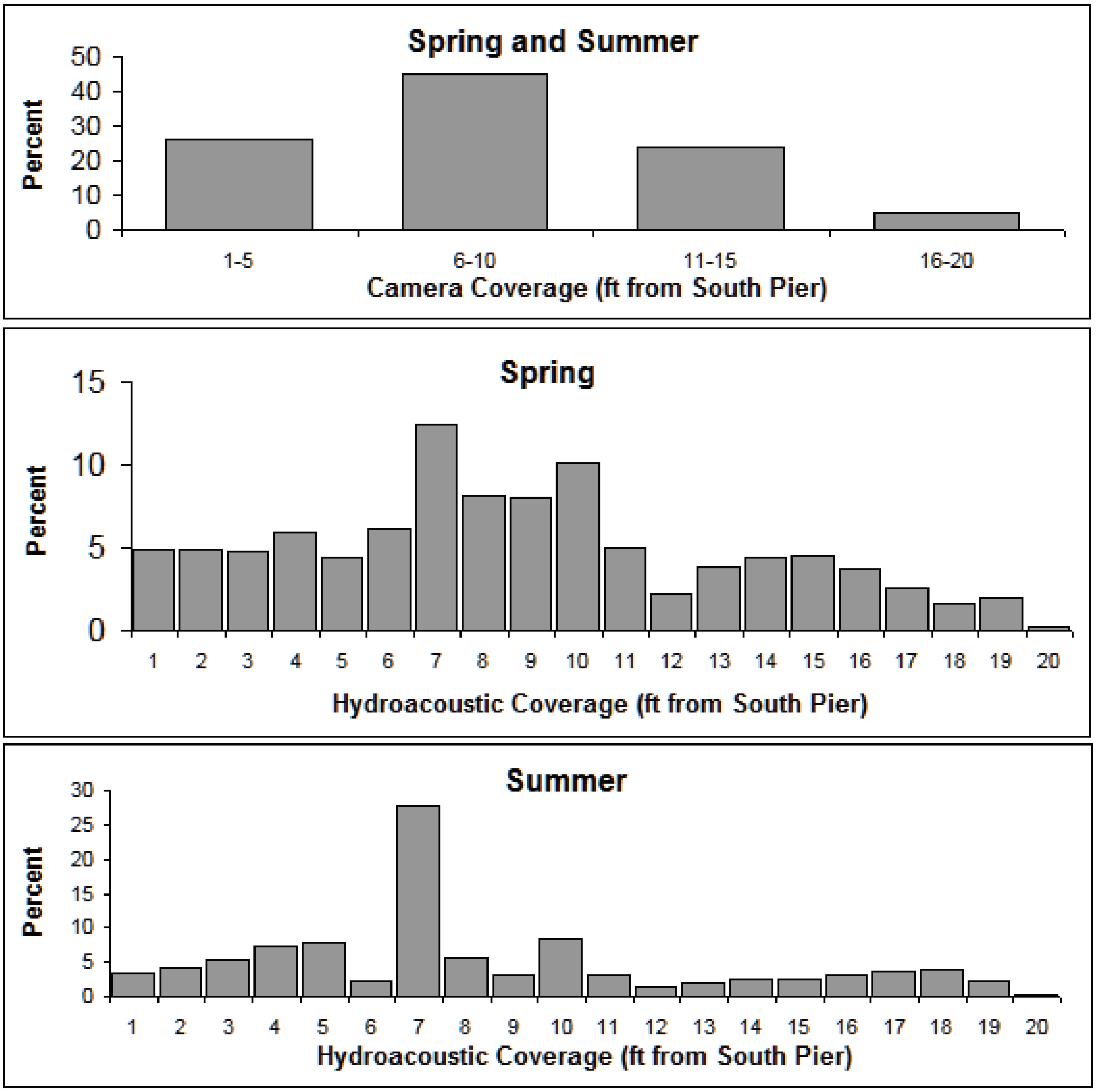

Figure 3.53. Plots of Horizontal Distribution of Fish Passage into Sluiceway Entrance 7A in Spring and Summer 2002 based on Video (Top) and Hydroacoustic Sampling (Middle and Bottom). Figure from Ploskey et al. 2003.

In spring 2004, the distribution of passage across the spillway did not follow the distribution of corresponding discharge, contrasting with the passage/discharge distributions observed at B1 (Figure 3.54). Spill bays that passed large volumes of water did not pass large numbers of fish. More fish passed through Spill Bay 16 than any other bay in the spring. In the summer, almost 16 million juvenile salmonids passed the Bonneville Dam (Figure 3.54). The horizontal distributions of passage for B1, the spillway, and B2 were estimated at 16%, 33%, and 51%, respectively, following the proportion of associated discharge through those structures. At B1, passage at the three sluiceways accounted for 38% of the total fish passed there, a 5% increase over what was observed in spring.

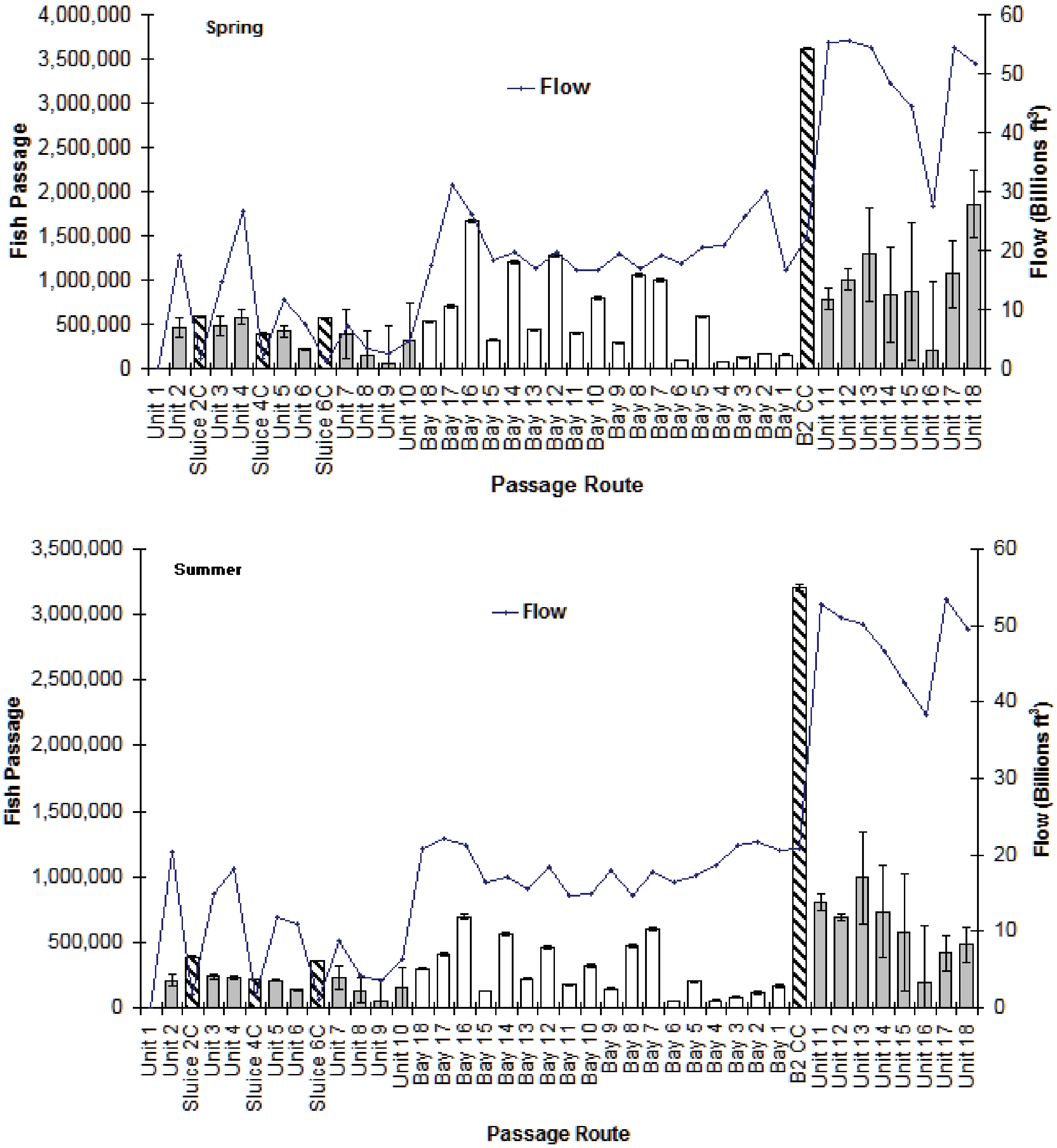

Figure 3.54. Estimated Fish Passage and Flow through All Sampled Routes at Bonneville Dam in Spring and Summer 2004. Turbine units are shown in light gray, spill bays in white, and surface passage routes (B1 sluiceways and B2 CC) in crosshatched black and white. Turbine Unit 1 did not operate in spring and summer 2004. Error bars represent 95% confidence limits on hydroacoustic estimates. The lines represent total spring and summer discharge by passage route (from Ploskey et al. 2005).

The horizontal distribution of fish densities in spring and summer 2004 suggests that each of the surface passage routes passed higher densities of fish than any one turbine unit or spill bay (Figure 3.55).

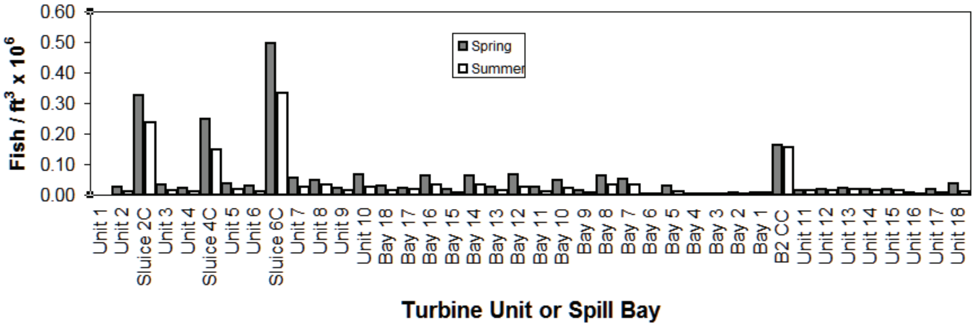

Figure 3.55. Fish Passage Density by Route in Spring and Summer 2004.

In 2005, the proportion of flow and fish passage at B1 was lower in summer than it was in spring since more flow was routed from B1 to the spillway in summer (Figure 3.56).

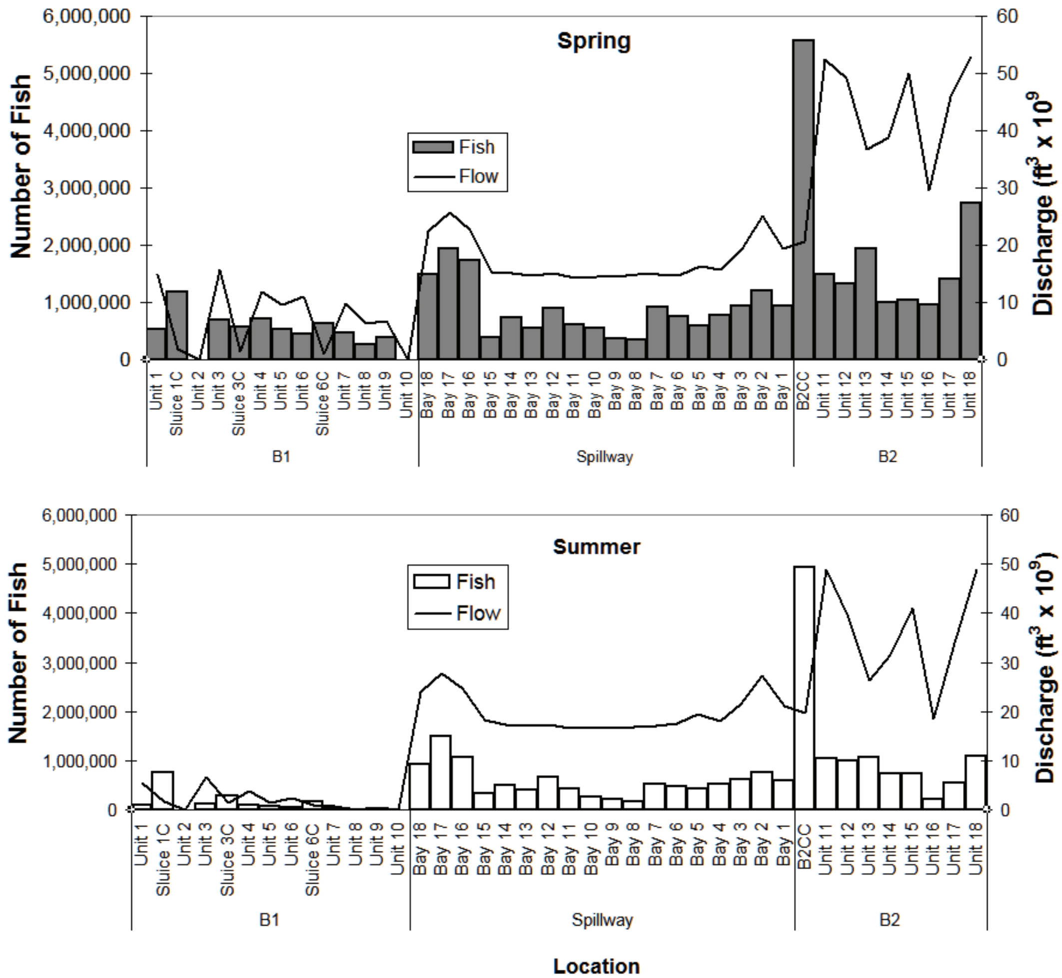

Figure 3.56. Estimated Fish Passage and Flow through all Sampled Routes at Bonneville Dam in Spring and Summer 2005. The lines represent total spring and summer discharge by passage route (from Ploskey et al. 2006c).

In 2005, the highest fish densities were observed at the surface flow outlets in both spring and summer compared to the other outlets (Figure 3.57). Passage densities were lower in summer than in spring 2005.

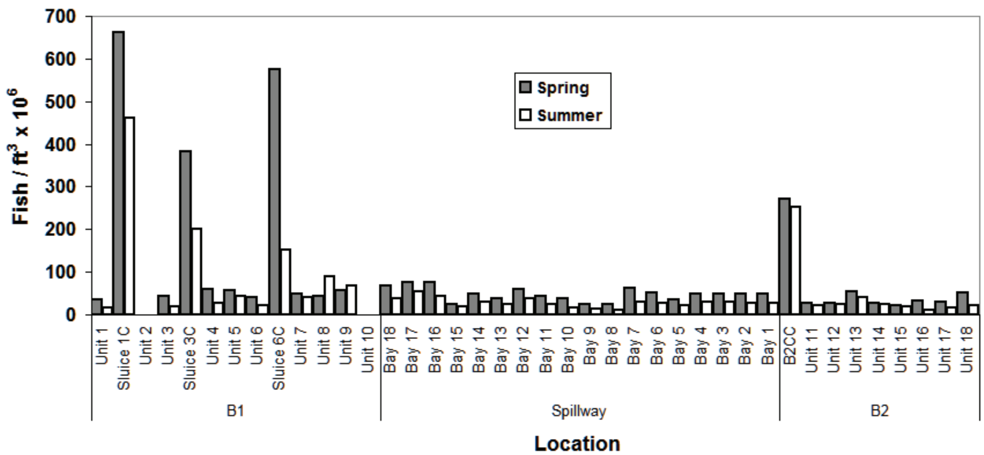

Figure 3.57. Fish Passage Density by Route in Spring and Summer 2005

3.5.2.1.2 Radio Telemetry

Holmberg et al. (1996) reported there was no apparent pattern of distribution of fish passage at B1 in 1996. About two-thirds of the yearling Chinook salmon last detected at B1 passed on the north side of the powerhouse and about 60% of the subyearling Chinook salmon also passed on the north side. No radio-tagged fish passed through the sluiceway in 1996.

In 1997, of the hatchery and wild steelhead and yearling and subyearling Chinook salmon last detected at B1, the majority passed through turbine units at the north half of the powerhouse relative to the south side (Hensleigh et al. 1999). Of the fish that passed B1 in spring of 1997, 16% (12 of 73) of hatchery steelhead, 17% (1 of 6) wild steelhead, and 16% (6 of 37) of yearling Chinook salmon passed through the sluiceway. Sluiceway passage for subyearling Chinook salmon was unknown due to gear limitations.

Hansel et al. (1999) reported that, of the 174 hatchery steelhead passing B1 in 1998, 64% passed north of the wing wall, 16% passed either under or through the PSC, 18% passed south of the PSC, and about 2% passed through the navigation lock. Of the 144 yearling Chinook salmon passing B1, 56% passed north of the wing wall, 16% passed either under or through the PSC, 26% passed south of the PSC and about 1% passed through the navigation lock. Of 108 subyearling Chinook salmon passing B1 in 1998, 70% passed north of the wing wall, 13% passed either under or through the PSC, 16% passed south of the PSC, and about 2% passed through the navigation lock.

Plumb et al. (2001) portioned the passage distribution at B1 in 1999 by north of the wing wall, through or under the PSC (Units 3-6), and south of the PSC. The majority of both hatchery steelhead (68% of 265 fish) and yearling Chinook salmon (53% of 200 fish) passed B1 through the north portion of the powerhouse. Plumb et al. (2001) observed that 14% of steelhead and 25% of yearling Chinook salmon passed via the PSC and 19% of steelhead and 22% of yearling Chinook salmon passed via the south side of the powerhouse.

In 2000, of the hatchery steelhead passing B1, 44% (of 399 fish) passed via the sluiceway, 33% were guided into the juvenile bypass system, and 23% passed through the turbine units (Evans et al. 2001a). Almost equal numbers of yearling Chinook salmon were guided (36% of 431 fish) and unguided (35%) at

B1 and 29% passed through the sluiceway. Based on total turbine passage (guided and unguided fish), Unit 2 passed the greatest numbers of steelhead whereas Unit 5 passed the greatest number of yearling Chinook salmon. Fifty-five percent of hatchery steelhead and 56% of yearling Chinook salmon entered the southern half of the PSC (units 1-3). Of 214 subyearling Chinook salmon passing B1, 68% passed though the sluiceway, 9% were guided into the bypass, and 23% passed through turbine routes (Evans et al. 2001b). Unit 5 passed the greatest number of total turbine-passed subyearling Chinook salmon. Slightly more than half (54%) of subyearling Chinook salmon passed through the northern half of the PSC (units 4-6).

In the drought year of 2001, B1 received about 7% of the total discharge through the Bonneville Project. Of the 47 yearling Chinook salmon that passed B1 through known passage routes, 76% passed through the sluiceway, 13% passed unguided through the turbines, and 11% were guided into the juvenile bypass system (Evans et al. 2001c). Of 30 subyearling Chinook salmon, 70% passed the sluiceway, 13% were guided into the bypass, 10% passed unguided through the turbines, and 7% passed through the adult ladder on Bradford Island (Evans et al. 2001d).

In 2002, of the 156 yearling Chinook salmon observed to pass through known routes at B1, 35% passed the sluiceway, 30% were guided into the bypass channel, 30% passed through turbine units, 4% passed the navigation lock, and 1% passed the project via the adult ladder (Evans 2003a). The majority of hatchery steelhead passed B1 through the sluiceway (65%), followed by guidance into the bypass (26%), and turbine passage (9%). Subyearling passage through B1 by location was dominated by the sluiceway (48%), followed by turbines (28%), the bypass (21%), and the navigation lock (1%; Evans et al. 2003b). Based on total turbine passage, subyearling Chinook salmon numbers peaked through Unit 10 and were lowest through Unit 3.

In spring 2004, B2 passed the largest percentage of fish (59% of yearling Chinook salmon and 66% of steelhead). The spillway passed 33% of yearling Chinook salmon and 25.5% of steelhead. Finally, B1 passed 8% of yearling Chinook salmon and 8.5% of steelhead. Of the fish passing through the first powerhouse, 53% of yearling Chinook salmon and 55% of steelhead passed into the sluiceway, with 46% of yearling Chinook salmon and 42% of steelhead passing unguided through the turbines. At the second powerhouse, 43% of yearling Chinook salmon passed unguided through the turbines, 36% passed through the B2CC, and 21% were guided to the downstream migrant bypass system (DSM). Seventy-four percent of steelhead were captured by the B2CC, 16% were passed unguided through the turbines, and 10% were guided into the DSM (Reagan et al. 2006, updated from 2005 report).

In summer 2004, as in the spring, the B2 passed the most subyearling Chinook salmon (60%), followed by the spillway (35%), and then B1 (5%). Of the B1 fish, 48% passed through the turbines unguided, 47% passed through the sluiceway, and 5% passed through the navigation lock. The majority of the fish passing B2 (49%) passed through the turbines unguided, while 39% passed through the B2CC, and 14% were guided to the DSM (Evans et al. 2006c, updated from 2005 report).

In spring 2005, the passage distribution was similar to 2004 with the majority of yearling Chinook salmon (56%) and steelhead (53%) passing through the B2, followed by the spillway (38% of yearling Chinook salmon and 39% of steelhead), and finally B1 passing 6% of yearling Chinook salmon and 8% of steelhead. Thirty-three percent of yearling Chinook salmon and 29% of steelhead passed into the sluiceway, and 65% of Chinook salmon and 70% of steelhead passed through the turbines unguided. Fish passing B2 were apportioned as follows: with 45% yearling Chinook salmon passing unguided through the turbines, 29% through the B2CC, and 26% guided into the DSM. A higher proportion of the steelhead (66%) were passed through the corner collector, 22% were unguided through the turbines, and 12% were guided to the DSM (Adams et al. 2006).

In summer 2005, the spillway passed the majority of subyearling Chinook salmon (51%), with the B2 accounting for 48%, and B1 only passing 1% of the subyearlings. Of all the tracked subyearlings passing through B1, 31% went through the turbines unguided, 59% passed through the sluiceway, and 10% entered the navigation lock. At B2, 46% passed through the turbines unguided, 40% were captured by the B2CC, and 14% were guided into the JBS (Adams et al. 2006).

3.5.2.2 Spillway

3.5.2.2.1 Hydroacoustics

Trends in the hydroacoustic distribution of fish passed at the spillway can be summarized by a three-year mean from data acquired in 2002, 2004, and 2005 when every bay was sampled (Figure 3.58). Another reason for using data for these years was that a new spill pattern was first implemented in 2002. The figure shows that trends were similar in spring and summer. There was slightly higher percent passage at units 16 and 17 than at most other bays, and this skew resulted in 40%-43% of fish passage through bays with 7-ft-elevation deflectors, when 33% would be expected based upon the percent of bays with 7-ft-elevation deflectors (bays 1-3 and 16-18). Survival data suggest that fish passing through bays with older 14-ft-elevation deflectors (57%-60% of passage through bays 4-15) may have lower survival than fish passing through bays with the new 7-ft-elevation deflectors (Counihan et al. 2003, 2006a).

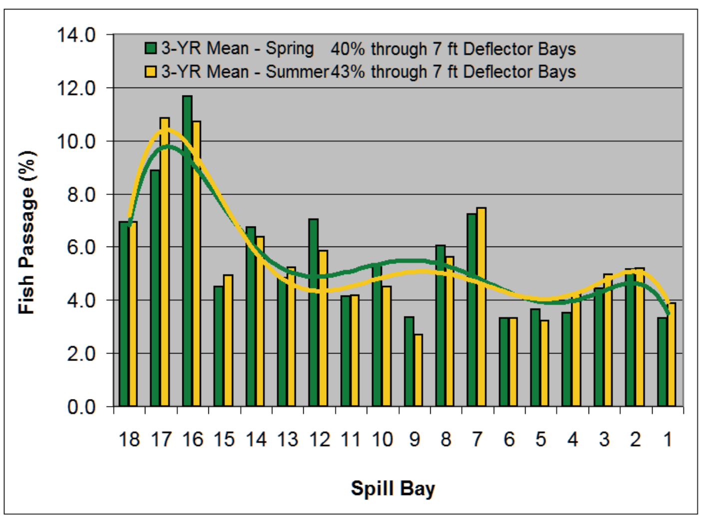

Figure 3.58. Fish Passage Distribution based on a Three-year Mean of Spring and Summer Estimates from 2002 through 2005 under New Spill Patterns

Ploskey et al. (2002a) provided the first horizontal distribution of passage estimates at the Bonneville spillway in 2000 using hydroacoustics and sampling of strata of 3-4 adjacent bays. In the spring, passage was distributed very unevenly with bays 2-4 passing the most fish followed by bays 11-14 and 8-10; the fewest fish passed bays 5-7 (Figure 3.49). In summer, the distribution of passage was slightly less varied with bays 11-14 passing the most fish followed by bays 2-4 and 8-10. As in spring, bays 5-7 passed the fewest fish (Figure 3.49). When fish passage densities (fish passing per unit volume) were examined, bays 11-14 passed the highest densities of fish in the spring and bays 15-17 passed the lowest densities in summer (Ploskey et al. 2002a).

In the drought year of 2001, only 16% of total discharge passed the spillway in the spring and 20% in the summer (Ploskey et al. 2002c). Based on sampled and interpolated estimates in 2001, spill bays 6, 12, 16, and 17 passed the most fish in the spring and in summer (Figure 3.50; Ploskey et al. 2002c).

Distribution of fish passage at the spillway in spring of 2002 indicated high variability across spill bays, with the southern half of the spill bays (bays 10-18) passing 13% more fish than the northern eight bays (Figure 3.51; Ploskey et al. 2003). Similar to the spring results, summer spill passage was unevenly distributed across spill bays, with the southern half passing 14% more fish than the northern half (Figure 3.51). Discharge was fairly evenly distributed across all bays in both seasons, so distribution patterns of fish passed per water volume (Figures 3.52) did not differ from total fish passage distributions.

In 2004, the distribution of passage across the spillway in spring did not follow the distribution of discharge there, contrasting with the passage/discharge distributions observed for B1 (Figure 3.54). Spill bays 2, 3, and 17 passed the greatest volumes of water relative to other spill bays but did not pass large numbers of fish. In fact, Bay 3 passed very few fish relative to the other spill bays. Spill bays 6-15 all passed similar volumes of water but disparate numbers of fish. More fish passed through Bay 16 than any other bay. The estimated distribution of passage across the spillway in the summer was similar to the spring distribution, with the highest passage occurring at Bay 16 and lowest passage numbers occurring at spill bays 4 and 6. As in spring, the horizontal distribution of passage in summer did not follow the distribution of discharge.

In 2005, during both sampling seasons, the percentage of the total fish that passed the spillway was similar to the percentage of discharge through the spillway (Figure 3.59). Within the spillway structure, however, fish passage was less related to discharge. In spring and summer, the south end of the spillway (bays 16-18) passed the highest number of fish (Figure 3.56). Fewer fish passed B1 in summer because flows had been diverted to the spillway resulting in lower flows at B1.

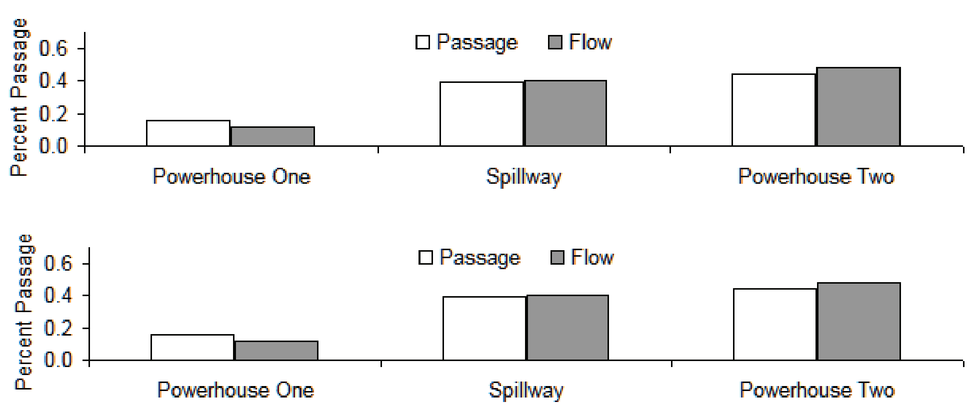

Figure 3.59. Percentage of Fish Passage and Discharge at Each Major Passage Structure in Spring (top) and Summer (bottom) 2005

3.5.2.2.2 Radio Telemetry

Numbers of radio-tagged fish detected at the spillway each season between 1996 and 1999 were only sufficient to provide a broad description of passage trends by north and south halves of the structure, and estimates in later studies were reported only as a proportion of total project passage (Table 3.21). At best, skews in spillway passage distributions could be described as weak in most years. In 1996, discharge was higher on the north and south ends of the spillway and tagged-fish passage was higher there than it was in the middle of the spillway (Holmberg et al. 1996). About 53% of 165 yearling Chinook salmon were last detected at the south half of the spillway, and 56% of 53 subyearling Chinook salmon were detected on the north half (Holmberg et al. 1996). In 1997, 403 of 596 hatchery steelhead (68%) and 153 of 240 yearling Chinook salmon (64%) passed through the south spillway, whereas subyearling Chinook passage was split evenly between the north and south halves of the spillway (Hensleigh et al. 1999). Spillway passage distributions were slightly skewed toward the north in spring of 1998 when 56% of 211 steelhead and 52% of 201 yearling Chinook salmon passed through the nine northern bays (Hansel et al. 1999), but the skew was a little stronger toward the north in summer, when 64% of 224 subyearling Chinook salmon passed bays 1-9. The distribution of spillway passage was slightly skewed toward the north in 1999, when the majority of both steelhead (67% of 250 fish) and yearling Chinook salmon (68% of 284 fish) passed through the north half of the spillway (Plumb et al. 2001).

Table 3.21. Proportion of Total Passage (in percent) through the Three Primary Passage Routes at Bonneville Dam (Evans et al. 2001a, b, and c; 2003a and b, Evans et al. 2006a, b, and c; Reagan et al. 2006; Adams et al. 2006).

		B1		Spillway		B2	
Year	Sampling Season	Chinook	Steelhead	Chinook	Steelhead	Chinook	Steelhead
2000	Spring		49	44	34		17
	Summer	30		69.5		0.5	
2001	Spring	4		16		80	
	Summer	6		2		92	
2002	Spring	8	6	57	55	35	39
	Summer	14		59		27	
2004	Spring	8	8.5	33	25.5	59	66
	Summer	5		35		60	
2005	Spring	6	8	38	39	56	53
	Summer	1		51		48	

3.5.2.3 Powerhouse 2

3.5.2.3.1 Hydroacoustics

Stansell et al. (1990) reported the first estimates for horizontal fish passage across a structure at Bonneville Dam based on hydroacoustics employed in 1989. All intakes of units 11 and 18 and the sluice chute were sampled in spring and summer. During the day in spring, Unit 18 passed a much higher proportion of fish than did Unit 11 or the sluice chute (Table 3.22). At night in the spring, Unit 18 passed more fish than the other two routes but not to the same degree as in the daytime. During the summer at night Unit 11 passed the most fish and the sluice chute the least of the three routes.

Among intakes in Unit 11, the distribution of passed fish was not uniform, with the greatest proportions at Intake A during the day in spring, Intake B at night in the spring, and Intake C at night in the summer (relative to the other intakes in the respective season and time period; Table 3.23). Among intakes in Unit 18, the distribution of passed fish was also non-uniform with Intake C passing the majority of fish in the spring, both during the day and at night, and Intake B passing much higher proportions than the other intakes during the night in the summer. Lateral passage into the sluice chute was skewed toward the middle third, with about half of all fish passing through the center during the day in spring and during the night both in spring and summer.

Table 3.22. Proportion of Fish Passed (%) by Season, Time Period and Passage Route in 1989. The daytime period is defined as 0900 to 1600 whereas night is defined as 1600 to 2300. Table created based on Appendices A1, A2, and C1 in Stansell et al. 1990.

Season	Time Per.	Unit 11	Unit 18	Sluice
Spring	Day	17	62	21
	Night	37	39	24
Summer	Night	52	33	15

Table 3.23. Proportion of Fish Passed (%) by Season, Time Period and Passage Route in 1989, for each Intake. The daytime period is defined as 0900 to 1600 whereas night is defined as 1600 to 2300. The ‘A’, ‘B’, and ‘C’ designations refer to the individual intakes within each turbine unit. Under the Sluice heading, ‘N’ = north, ‘M’ = middle, and ‘S’ = south. Table created based on Appendices A1, A2, and C1 in Stansell et al. 1990.

		Unit 11			Unit 18			Sluice		
Season	Time Per.	A	B	C	A	B	C	N	M	S
Spring	Day	38	30	32	25	33	41	23	58	19
	Night	33	37	30	22	36	42	26	48	26
Summer	Night	20	37	43	19	61	20	17	56	27

In 1996, Ploskey et al. (1998) sampled one intake (A, B, or C) at each turbine unit (11-18) at B2 and observed the highest proportions of passage at Unit 11 in the spring both during the day and at night

(Figure 3.60). During the day and night in spring, units 12 and 15 passed the smallest proportion fish. In the summer during the day, the majority of fish passed through units 12-14, with the fewest passing through Unit 15. At night in the summer, units 12 and 18 passed the most fish and again Unit 15 passed the least.

In 2000, Ploskey et al. (2002a) reported the horizontal distribution across all turbine units at B2. In the spring, total passage estimates indicated most fish passed units 13 and 15, while the fewest fish passed Unit 17 (Figure 3.49). In summer, units 11 and 18 passed the most fish (Figure 3.49) due to the fact that unit 12 was inoperable and units 13-17 were operated sparingly. Based on fish density in the spring, the horizontal distribution pattern was similar to that of total passage at B2.

Ploskey et al. (2002a) characterized the distribution of passage at B2 in 2001 as noticeably skewed toward the south half of the powerhouse in the spring (Figure 3.50) and a more even distribution in summer with peak passage at Unit 11 and the fewest fish passing at Unit 18 (Figure 3.50). Patterns of fish per flow volume differed from that of total passage, with the density highest and more evenly distributed across units 11-15 and the fewest fish passing Unit 18 in the spring (Figure 3.61). Based on fish density, most fish passed through units 13-15 in the summer.

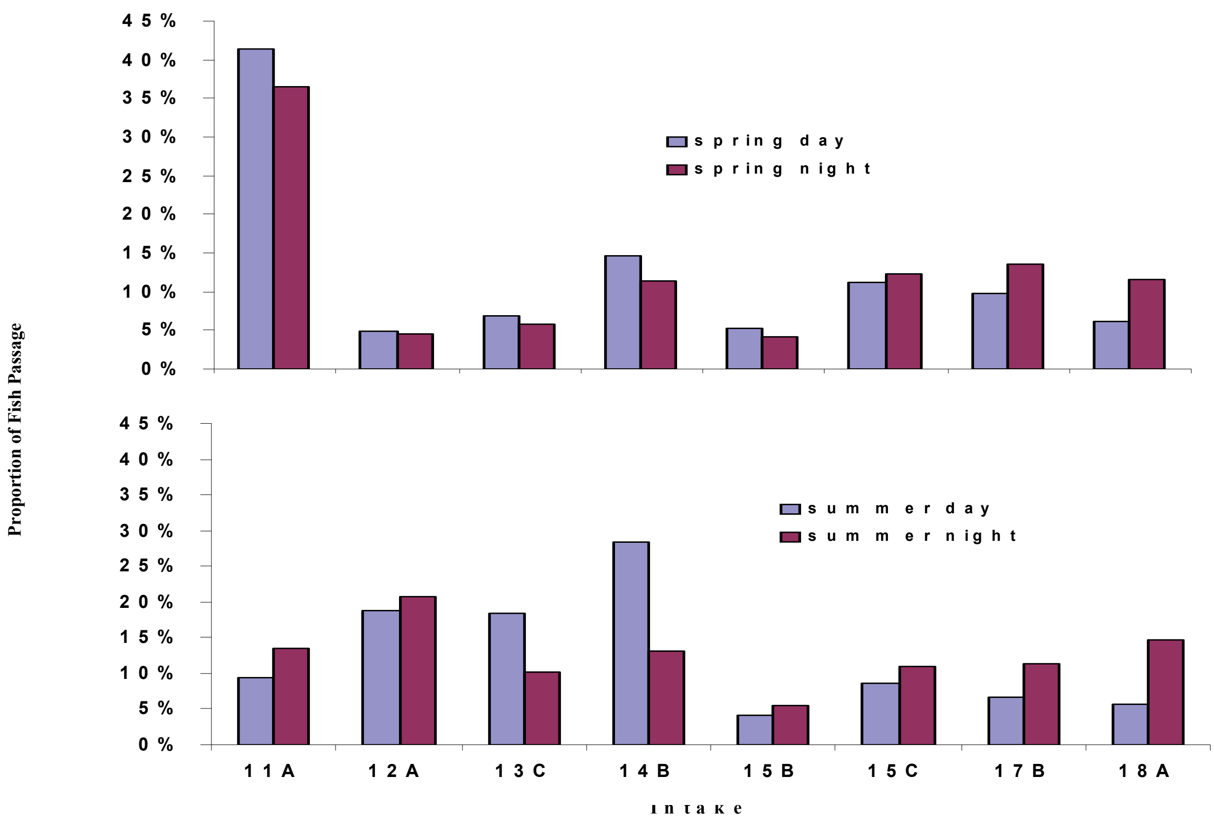

Figure 3.60. Proportional Fish Passage Across All Sampled Units at B2 in 1996 by Season and Time of Day. Plot created from Ploskey et al. 1998.

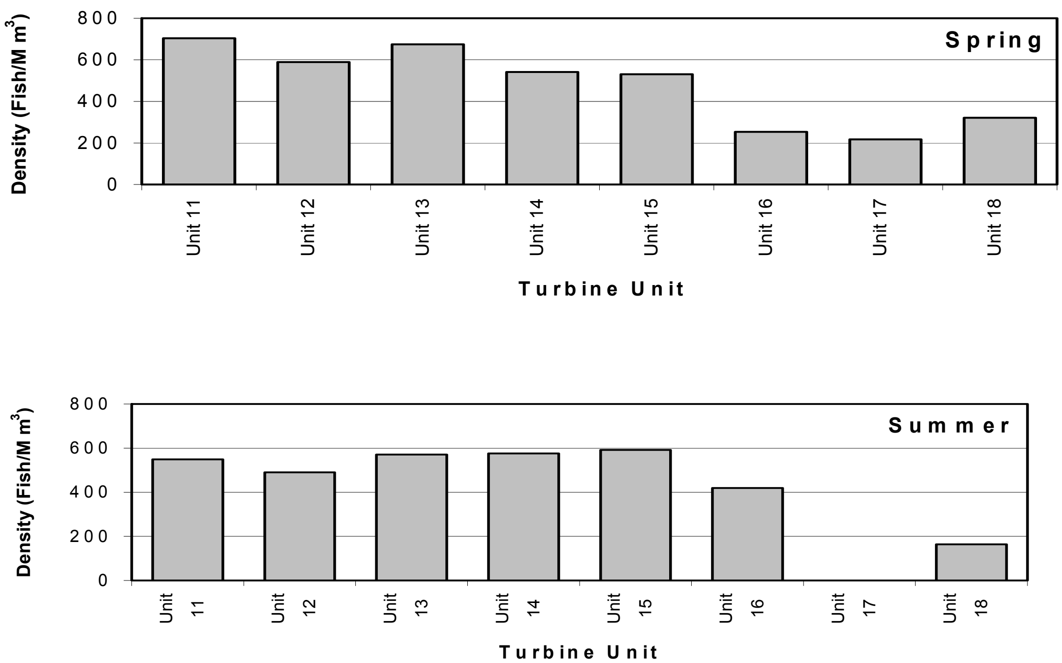

Figure 3.61. Horizontal distribution of Fish Passage Density, in Fish per Million Cubic Meters of Water, by Turbine Unit in Spring and Summer 2001. Unit 17 was inoperable during the summer season. Figure from Ploskey et al. 2002c.

In 2002, the distribution of fish passage at B2 in the spring was uneven with most fish passing through units 11 and 12, and the fewest fish passing units 15 and 18 (Figure 3.51; Ploskey et al. 2003). Summertime distributions again revealed a skew toward the south end of B2, with units 11 and 12 passing the greatest numbers of fish, and as in the spring, units 15 and 18 passing the fewest fish. The distribution patterns of fish density passage were similar to those of total passage for both spring and summer (Figure 3.52).

Estimated horizontal distributions of fish passage during the Spring Creek release during March 2004 indicated that the majority of both flow and fish passed through B2 for all three operational conditions tested [1) five days of 31,400 cfs spill with no B2CC operations; 2) four days of B2CC operation with no spill; 3) approximately seven days of no spill and no B2CC operation].

In spring 2004, the B2CC surpassed all other routes in terms of numbers of fish passed (Figure 3.54). At B2, the B2CC passed 31% of all fish in about 5% of all discharge through that powerhouse. Horizontal distribution of passage among turbine units at B2 generally followed flow with Unit 16 passing the least amount of water and the fewest fish relative to the other units. Units 11-13 and 17 all discharged higher volumes of water than did the other units, but Unit 18 passed the most fish.

In summer 2004, the horizontal distributions of passage for B1, the spillway, and B2 were 16%, 33%, and 51%, respectively. This generally matches the proportions of discharge through those structures. The B2CC had higher estimated passage than did any other individual route in summer (Figure 3.54), as was the case in spring. The B2CC passed 40% of all fish through that structure, an increase of 9% over that in spring with just 5% of the water passing B2. The horizontal distribution of passage among turbine units at B2 generally followed flow with Unit 16 passing the least amount of water and the fewest fish relative to the other units. Unit 13 passed the greatest number of fish, but Unit 17 passed the most water.

The horizontal distribution of fish passage into the B2CC also had a definite pattern with peak passage near the center of the B2CC entrance in both spring and summer and a second peak toward the south side of the collector in summer (Figure 3.62). The peak on the south side of the entrance in summer disappeared when data collected after July 4, which were contaminated by American shad detections, were excluded (Figure 3.63).

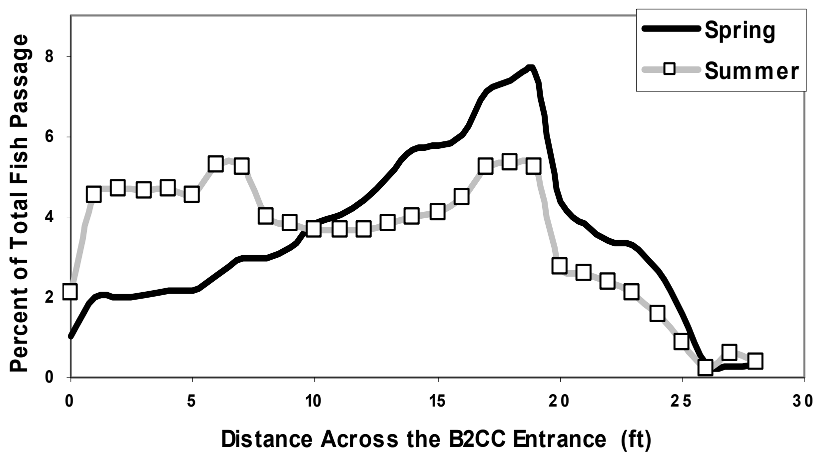

Figure 3.62. Horizontal Distribution of Fish Passing through the B2CC in Spring and Summer, 2004. The entrance narrows to a width of 15 ft, which would correspond to the 10 to 25 ft distance on the x axis. Zero to 10 ft is toward the south of the 15-ft wide opening, and 25 to 30 ft is toward the north.

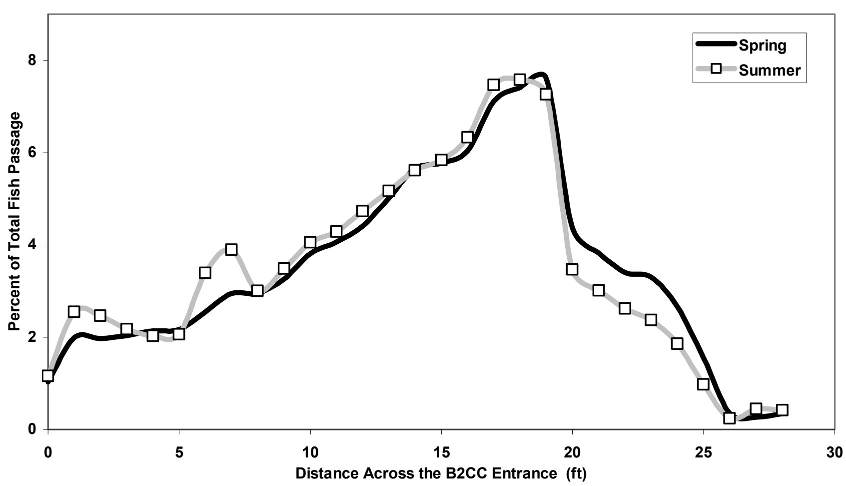

Figure 3.63. Horizontal Distribution of Fish Passing through the B2CC in Spring and Summer through July 3, 2004. The entrance narrows to a width of 15 ft, which would correspond to the 10- to 25-ft distance on the x axis. Zero to 10 ft is toward the south of the 15-ft-wide opening, and 25 to 30 ft is toward the north.

The horizontal distribution for each season (Figure 3.63) was produced primarily by a predominance of fish in the upper 5 ft of the water column, but the pattern of horizontal distribution certainly was not consistent among 4-ft depth strata (Figure 3.64). Trends in spring and summer were similar within depth bins, except for some anomalous peaks toward the south end of the entrance at depths of 9 to 20 ft in summer, which could be removed by dropping data collected after July 4. Over 95% of the fish passed in the upper 4 ft of the water column, which explains why the trend in the top plot of Figure 3.64 is very similar to the trend in the composite horizontal distribution (Figure 3.63).

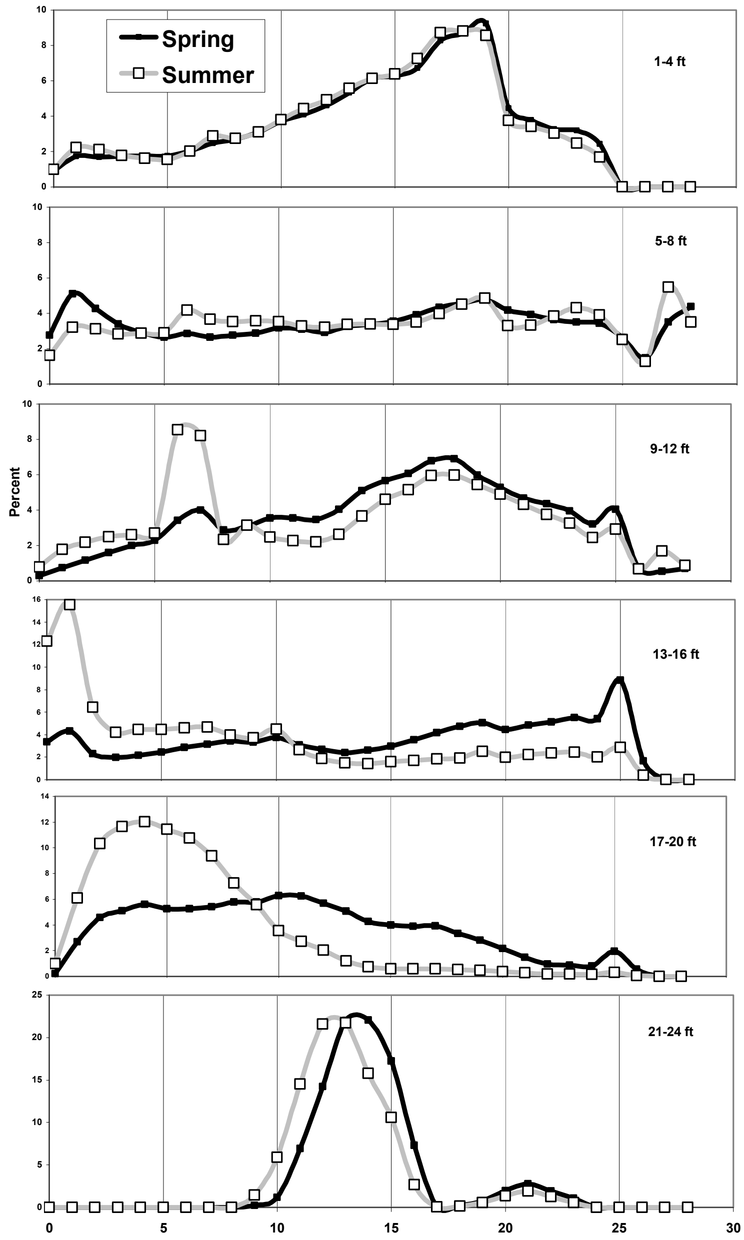

Figure 3.64. Horizontal and Vertical Distribution of Smolt-Sized Fish Upstream of the B2CC Entrance in Spring and Summer 2004. The entrance narrows to a width of 15 ft, which would correspond to the 10 to 25 ft distance on the x axis. Zero to 10 ft is toward the south of the 15-ft-wide opening, and 25 to 30 ft is toward the north.

In spring and summer 2005, most fish passed at the B2CC and at B2 units 11-13 and density for the most part paralleled route-specific discharge. The horizontal distribution of fish passage at the B2CC was highest in the center of the entrance during spring and slightly skewed toward the south during the summer (Figure 3.65).

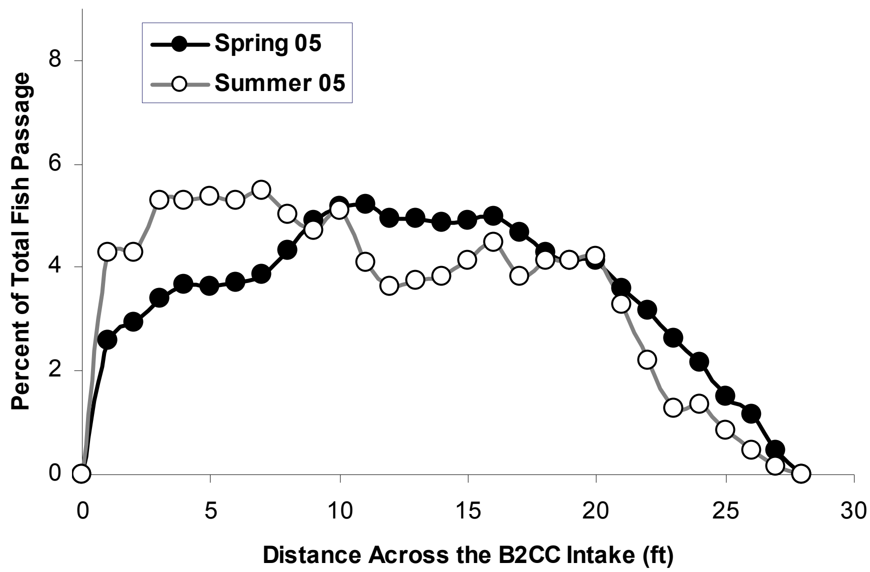

Figure 3.65. Horizontal Distribution of Fish Passage at the B2CC.

3.5.2.3.2 Radio Telemetry

Holmberg et al. (1996) reported that despite uniform flow distribution at B2 in 1996, most yearling Chinook salmon passed through the south end units 11-13. Unlike with yearling fish, slightly more than half the subyearling Chinook salmon passed through turbine units at the north end of B2. Sluice chute passage was not observed for either yearling or subyearling fish.

In 1997, the south half of B2 passed the majority of subyearling Chinook salmon (64 of 101) while the north half passed the majority of wild steelhead (2 of 2) and yearling Chinook salmon (8 of 15); equal numbers of hatchery steelhead (4) passed each half (Hensleigh et al. 1999). Based on opened/closed sluice chute test conditions, 37 subyearling Chinook salmon passed B2 during the former condition and 64 passed B2 during the latter condition. The distribution of last detections during sluice chute open conditions was significantly different when the sluice chute was closed (P=0.002) indicating a shift towards the south end of B2 when the sluice was open. The sample size was too small for spring migrants to examine differences during sluice chute conditions (Hensleigh et al. 1999).

Passage at B2 in 1998 indicated the south half of the powerhouse passed the majority of all migrants (60% of 141 steelhead, 57% of 138 yearling Chinook salmon, and 51% of subyearling Chinook salmon; Hansel et al. 1999). When the sluice chute was open, Hansel et al. (1999) reported 59% of 85 juvenile steelhead, 45% of 69 yearling Chinook salmon, and 37% of 54 subyearling Chinook salmon passed through the chute. As in 1998, the south half of B2 passed the majority of all migrants (66% of 152 steelhead and 57% of 204 yearling Chinook salmon) in 1999 (Plumb et al. 2001).

Evans et al. (2001a) reported for year 2000 slightly more steelhead (55%) passed guided through B2 than were unguided, contrasting with yearling Chinook salmon which passed a majority (60%) unguided through the powerhouse. Based on total turbine passage, Unit 11 passed the majority of both spring migrants. One percent of yearling Chinook salmon and no steelhead were observed to pass through the sluice chute, which was operated minimally in the spring of 2000. Of the four subyearling Chinook salmon passing B2 in 2000, three passed unguided through turbines and one was guided into the bypass system (Evans et al. 2001b).

In 2001, of the 915 yearling Chinook salmon that passed through known routes at B2, 54% passed unguided through the turbines and 46% were guided into the juvenile bypass (Evans et al. 2001c). Overall total turbine passage (guided and unguided) for yearling Chinook salmon across all spill conditions peaked at Unit 13. Examining total turbine passage under 37% and 2% spill conditions reveals a peak in passage through Unit 13 during the higher spill level and a peak at Unit 14 during the lower spill level. Of the 479 subyearling Chinook salmon passing B2, 65% passed unguided through the turbine units and the remaining 35% were guided into the bypass (Evans et al. 2001d). Total turbine passage peaked at Unit 16 for subyearling Chinook salmon.

Evans et al. (2003a) reported yearling Chinook salmon passage at B2 to be comprised of 63% unguided through turbines and 37% guided into the bypass system in 2002. Hatchery steelhead passage contrasted with yearling Chinook salmon, with 59% guided into the bypass and 41% passing through turbine units. Total turbine passage peaked for yearling Chinook salmon at Unit 11 and for steelhead at Unit 13. Unit 18 passed the fewest fish of both species in 2002. Of the 682 subyearling Chinook salmon passing B2 through known routes, 53% passed into turbine units while 47% were guided into the bypass channel (Evans et al. 2003b). Total turbine passage for subyearling Chinook salmon peaked through Unit 14 and Unit 18 passed the fewest numbers of the summer migrants.

Of the yearling Chinook salmon that passed at B2 in spring 2004, 43% passed unguided through the turbines, 36% passed through the B2CC, and 21% were guided into the DSM (Reagan 2006). A larger percentage of the steelhead at B2 (74%) passed through the corner collector, while 16% passed unguided through the turbines, and 10% were guided into the DSM. In summer 2004, 49% passed unguided through the turbines, 37% passed through the corner collector, and 14% were guided into the DSM.

In spring 2005, the 45% of yearling Chinook salmon that passed at B2 were unguided through the turbines, 29% passed through the corner collector, and 26% were guided into the DSM. For steelhead passing at B2, 66% passed through the corner collector, 22% passed unguided through the turbines, and 12% were guided into the DSM. The greatest discharge occurred at B2; thus, more than half of both species entered the forebay of B2. In summer 2005, 46% of the subyearling Chinook salmon passed unguided through the turbines, 40% passed through the B2CC, and 14% were guided into the DSM. As in previous years, the proportion of discharge allocated among B1, B2, and the spillway appeared to dictate which dam area fish entered and passed.

3.5.2.4 Comparison of Hydroacoustics and Radio Telemetry Estimates

Prior to 2000, estimates of passage at B1 were not collected or reported in a manner conducive for comparison across techniques. Passage estimates at B1 from hydroacoustic and radio telemetry studies in 2000 yielded contrasting results. Based on hydroacoustic methods, Ploskey et al. (2002a) reported that

Units 4 and 9 passed the greatest number of fish in spring and summer 2000. Based on radio telemetry for spring migrants, Unit 2 passed the greatest number of hatchery steelhead, and yearling Chinook salmon passage peaked through Unit 5 (Evans et al. 2001a). Summer 2000 subyearling Chinook salmon passage also peaked through Unit 5 (Evans et al. 2001b). Horizontal distribution estimates at B1 for 2001 could not be compared across methods since so few radio-tagged fish passed the structure that turbine unit-specific passage was not reported (Evans et al. 2001c).

The B1 sluiceway dominated passage for both seasons based on both hydroacoustic and radio telemetry techniques in 2002. Ploskey et al. (2003) reported that, within B1, the sluiceway passed 33% and 30% of all fish for spring and summer, respectively. Radio-telemetry results on B1-passed fish showed that 35% of yearling Chinook salmon and 65% of hatchery steelhead of moved through the sluiceway in the spring of 2002 (Evans et al. 2003a), as did 47% of subyearling Chinook salmon in summer of the same year (Evans et al. 2003b). Too few spring migrants passed B1 to effectively assess passage through individual turbine units (Evans et al. (2003a) but for subyearling Chinook salmon in the summer, Unit 10 passed the greatest numbers while Unit 3 passed the fewest number (Evans et al. 2003b). Estimates for hydroacoustics did not concur, instead showing summer passage peaking through units 2 and 7, with the fewest fish passing units 1 and 10 (Ploskey et al. 2003).

For research years 2002 through 2005, Ploskey et al. (2003, 2005, and 2006c) provided hydroacoustic estimates of passage through individual bays at the Bonneville Dam spillway. During that same time period, estimates of passage for radio-tagged migrants through the spillway were limited to proportions of total passage through Bonneville Dam. Passage across spill bays was not reported; therefore, a comparison of the horizontal distribution of fish passage among methods could not be accomplished.

Estimates of the horizontal distribution of fish passage at B2 were generally similar across methods in 1996. Ploskey et al. (1998) observed peak passage through Unit 11 in the spring using hydroacoustics, which matched up with Holmberg et al. (1996) who reported most yearling Chinook salmon passed through the south end units 11-13. Summertime passage based on hydroacoustics indicated units 12-14 passed the most fish during the day and units 12 and 18 passed the most fish during the night (Ploskey et al. 1998). To some extent, radio telemetry estimates concurred with those from hydroacoustics as Holmberg et al. (1996) reported slightly more than half of the subyearling migrants passed B2 at the north end. However, radio telemetry passage estimates were not reported separately by day and night time periods.

Different passage trends at B2 in 2000 were observed between the two monitoring techniques as Ploskey et al. (2002a) reported peak passage in the spring through units 13 and 15 with hydroacoustics. Radio telemetry indicated hatchery steelhead and yearling Chinook salmon passed in the greatest numbers through Unit 11 in spring (Evans et al. 2001a). Unit 17 passed the fewest spring migrants based on hydroacoustics (Ploskey et al. 2002a), while Evans et al. (2001a) reported Unit 15 as passing the fewest steelhead and Chinook salmon. The sample size was too small to report unit-specific turbine passage for radio-tagged subyearling Chinook salmon.

Hydroacoustic estimates for springtime passage in 2001 indicated a skew toward the south half of B2, with a peak in passage at Unit 11 (Ploskey et al. 2002c). Radio telemetry estimates showed peak passage at Unit 13 for yearling Chinook salmon in 2001 (Evans et al. 2001c). The two methods did show agreement, however, on unit 18 passing the smallest proportion of spring migrants. Summertime passage estimates at B2 collected with hydroacoustics indicated peak passage density through Units 13-16 (Ploskey et al. 2002c) while radio-tagged subyearling Chinook salmon passed the in greatest numbers through Unit 16 (Evans et al. 2001d). As in spring, Unit 18 passed the fewest fish in summer according to both monitoring techniques.

Springtime lateral passage trends at B2 in 2002 were to some degree similar across methods (Figure 3.66). Ploskey et al. (2003) estimated peak passage with hydroacoustics through units 11 and 12, concurring with Evans et al. (2003a) who reported peak passage through Unit 11 for radio-tagged yearling Chinook salmon. Radio-tagged hatchery steelhead, however, passed in greatest numbers through Unit 13. As in 2001, Unit 18 passed the fewest spring migrants based on both hydroacoustics and radio telemetry. In the summer of 2002, the Ploskey et al. (2003) hydroacoustic study reported peak passage occurred through units 11 and 12, with the fewest fish passing through units 15 and 18. In contrast, the Evans et al. (2003b) radio telemetry study indicated subyearling Chinook salmon passed in greatest numbers through Unit 14, with Unit 18 again passing the fewest numbers of summer migrants.

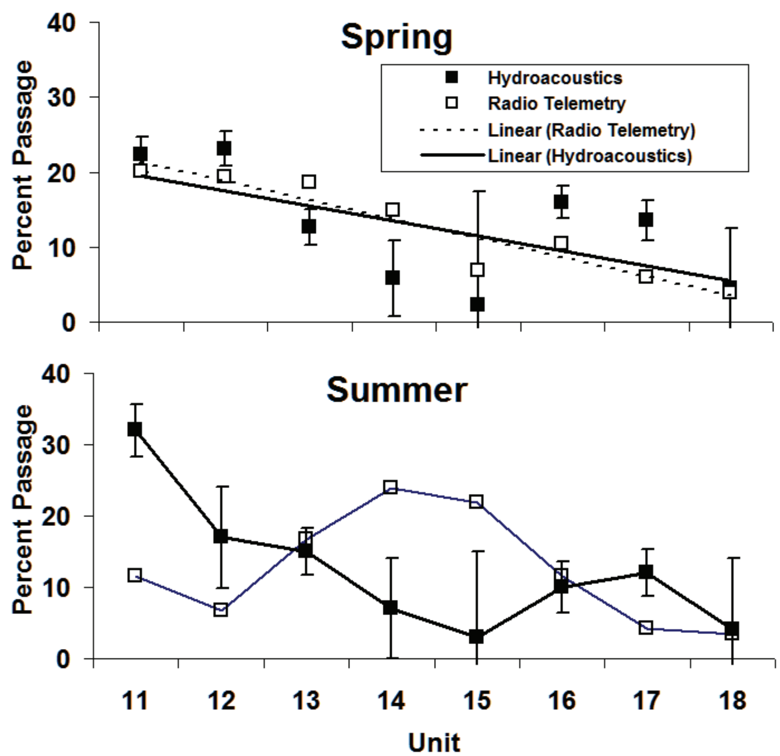

Figure 3.66. Plots of the Percent of Total Passage Estimated by Hydroacoustics and Radio Telemetry at B2 in Spring and Summer 2002. Estimates were based on the percent of passage during the same days. Vertical bars on hydroacoustic estimates are 95% confidence limits. Figure from Ploskey et al. 2003.

In 2004 and 2005, the distribution of passage at B2 included passage at the B2CC, and hydroacoustic and radio telemetry estimates of passage were correlated (Figure 3.67), with similarities in distribution patterns readily evident (Figure 3.68). The correlation in distribution pattern was diminished by divergent estimates for Unit 17 in spring and Unit 18 in both seasons. The correlations between estimates by the two methods were stronger in summer than they were in spring, perhaps because subyearling Chinook salmon made up most of the run-at-large and all of the tagged fish population in summer.

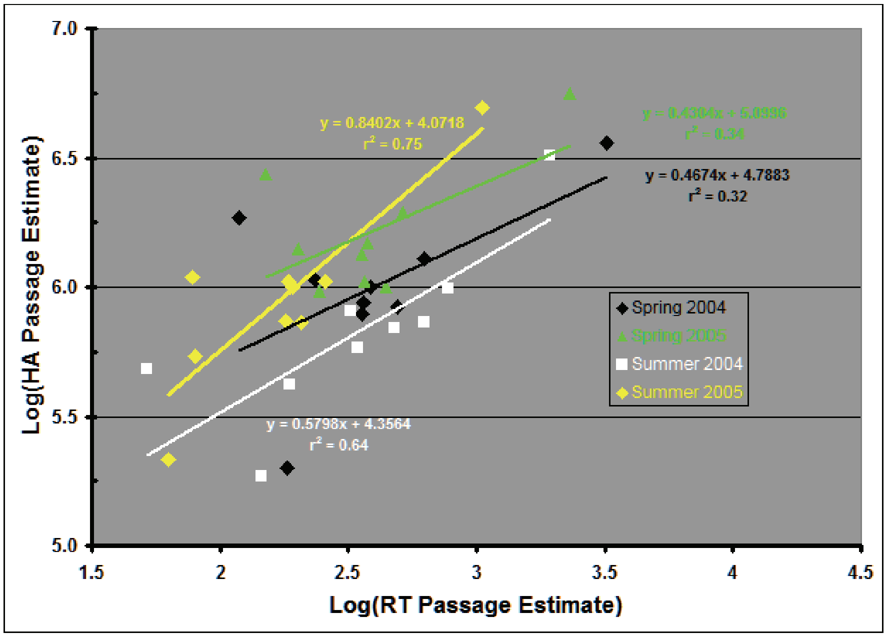

Figure 3.67. Correlations between Hydroacoustic and Radio Telemetry Estimates of Percent Passage by Route at B2 in 2004 and 2005.

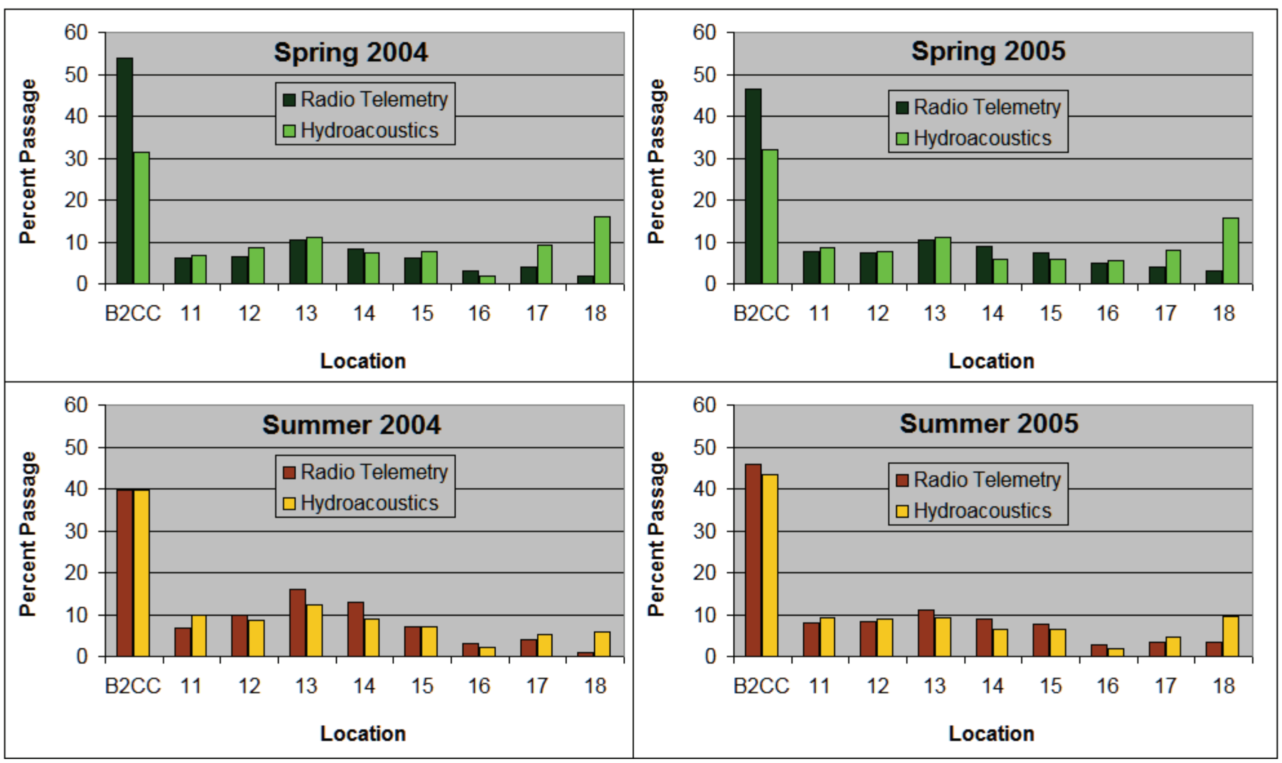

Figure 3.68. Distribution in Percent Passage Among B2 Routes in Spring and Summer of 2004 and 2005, as Estimated by Radio-Telemetry and Hydroacoustic Methods.

3.5.3 Vertical Distributions

3.5.3.1 Turbines

Ploskey et al. (2001b) used hydroacoustics to sample Unit 5 in 1999 and reported that during 5-ft slot treatments in-turbine vertical distributions of fish were similar in spring and summer (Figure 3.69). There were slight differences in guided and unguided fish distributions between seasons, with guided fish slightly deeper in spring than in summer, contrary to unguided fish where peak concentrations were slightly deeper in summer than in spring.

In 2001, Ploskey et al. (2002c) used hydroacoustics to examine the vertical distribution of smolt-sized fish inside Intake 10B at B1. The distribution in the spring was skewed toward higher elevations with a slight proportional increase near the floor of the turbine intake (Figure 3.70). The summer distribution was skewed toward both higher elevations and the intake floor (Figure 3.71).

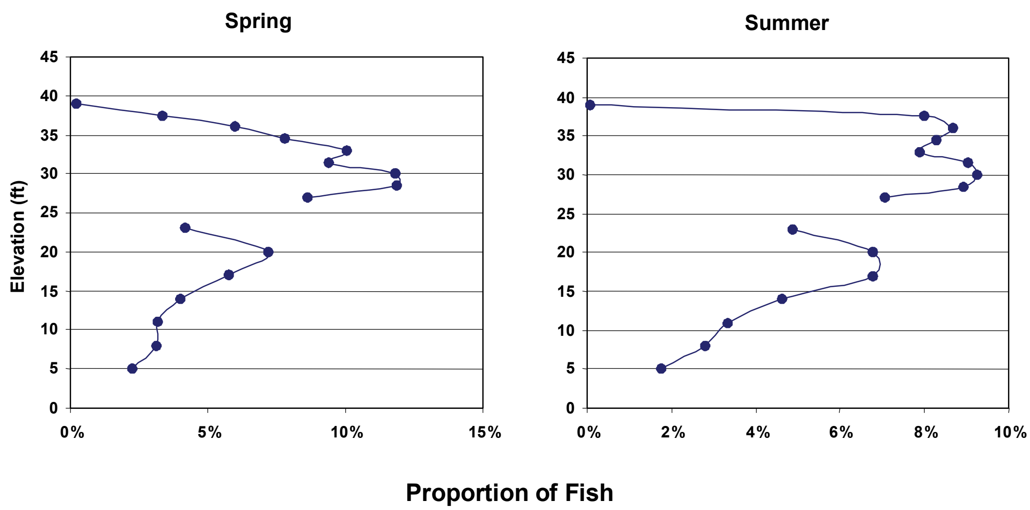

Figure 3.69. Vertical Distributions of In-Turbine Fish Passage Estimates during 5-ft Slot Treatments for Spring and Summer 1999. Plots illustrate distributions of guided (upper portions of distributions) and unguided (lower portions) fish. The gaps between the upper and lower portions reflect the elevations that were not sampled. Figure from Ploskey et al. 2001b.

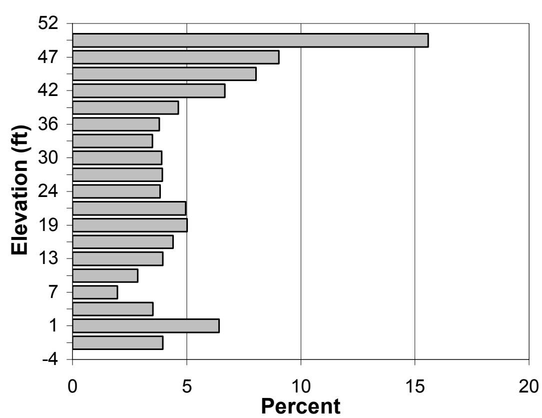

Figure 3.70. Vertical Distribution of Smolt-Sized Fish Detected Inside Intake 10B in Spring 2001. Figure from Ploskey et al. 2002c.

With radio telemetry, Evans et al. (2001a) determined the depth of entrance into the PSC using the last detection received by underwater antennas along the face of the PSC before the first detection inside the PSC. In 2000, 73% of 211 hatchery steelhead were observed to enter the PSC at shallow depths (0 to 6.5 m). In contrast, 55% of yearling Chinook salmon entered the PSC at deep depths (6.5 and 13 m). At night the majority of both species entered the PSC at deep depths while during the day 84% of steelhead and 48% of yearling Chinook salmon entered at shallow depths. Of the 204 subyearling Chinook salmon detected at the PSC entrance, 52% approached at deep depths (Evans et al. 2001b). Subyearling Chinook salmon differed in their approach depth by time of day: 59% of daytime approaches occurred at deep depths while at night 69% of approaches occurred at shallow depths.

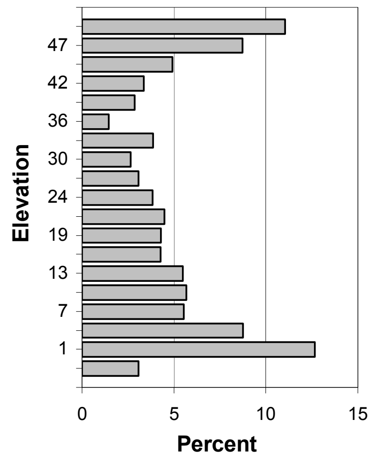

Figure 3.71. Vertical Distribution of Smolt-Sized Fish Detected Inside Intake 10B in Summer 2001. Figure from Ploskey et al. 2002c.

For research year 2001, the gatewell and vertical barrier screen at Intake 15B were modified to increase flow into the gatewell. Ploskey et al. (2002c) reported the vertical distribution of fish inside Intake 15B to be similar in pattern across seasons but spring fish were distributed more frequently at higher elevations and less frequently at lower elevations than summer fish (Figure 3.72).

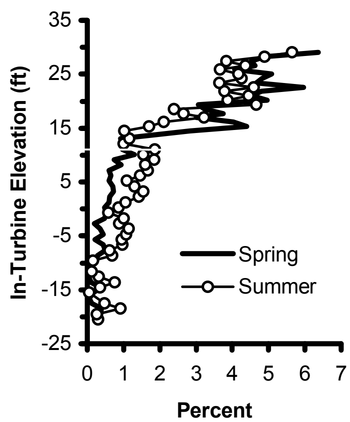

Figure 3.72. Vertical Distribution of Smolt-Sized Targets Inside Modified Intake 15B for Spring and Summer 2001. Figure from Ploskey et al. 2002c.

The estimated vertical distribution patterns of fish within turbine intakes at B1 in 2004 were multi-modal during both spring and summer, with modes occurring at a shallow elevation of about 60 ft. mean sea level, just above midwater (about EL 37 ft), and near the bottom of the turbine entrance (at about El. 6 ft) (Figure 3.73). In the spring, we estimated that the greatest proportions of fish were detected near the lowest elevations, whereas in summer fish were distributed at highest frequencies near the highest elevations.

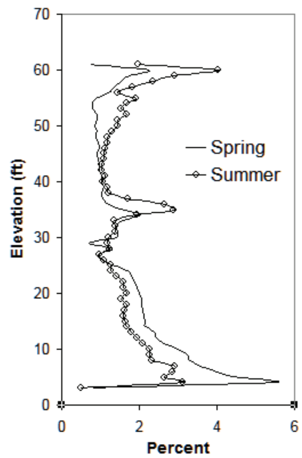

Figure 3.73. Estimates of Vertical Distributions of Fish within Turbine Intakes at Bonneville Dam First Powerhouse in Spring and Summer 2004

Vertical distribution patterns of fish passing the spillway were similar in spring and summer, characterized by a general increase in percentages with increasing depth. However, a slight decrease in percent passage with increasing depth is evident in spring and summer between elevations 37 and 39 ft. Both distributions peaked at about 36 ft elevation, with the peak slightly higher in spring than in summer.

The estimated vertical distributions of fish within turbine intakes at B1 also were multi-modal in 2005, with peaks in fish-passage percentages near the top of the intakes (about elevation 60 ft.), at about the middle of the intakes (elevation 36 ft.), and near the bottom of the intakes (Figure 3.74). The largest peak was near the bottom of the intake in each season. A similar pattern was observed in 2004, with a prominent peak near the bottom of the intakes that rivaled the peak near the ceiling in spring and exceeded the ceiling peak in summer.

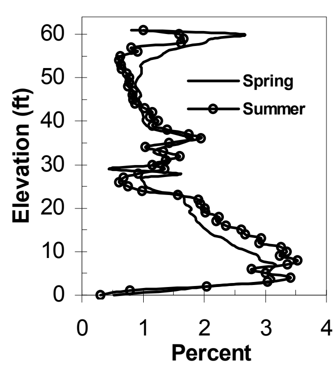

Figure 3.74. Vertical Distributions of Fish within Turbine Intakes at B1 in 2005.

Hydroacoustic sampling at B1 in 2004 and 2005 differed from that in earlier years so an effort was made in 2005 to standardize vertical distribution data with what was collected before 2004. For example, the average B1 vertical distribution was adjusted in 2005 by moving fish detected above Elevation 47 ft and near the trash racks deeper into the intake which corresponded to the uppermost strata sampled in 2002 and earlier years (EL 41-47 ft). This standardization of maximum elevations to those sampled in 2001 and 2002 restored the predominance of fish passage in the upper water column for the 2005 data (Figure 3.75), although a substantial percent of fish passed deep through B1 turbines. Data from 2002 (Figure 3.76) also show sizeable percentages of fish passing deep, as do data from 2001 (Ploskey et al. 2002c).

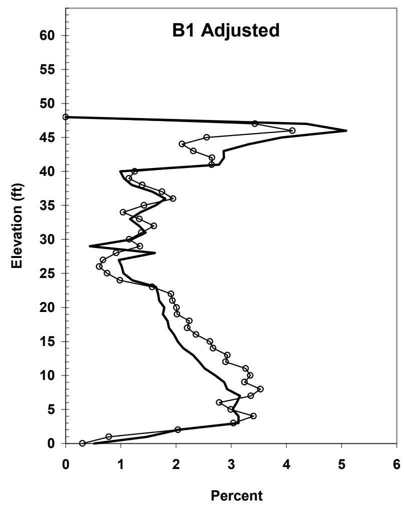

Figure 3.75. Average Vertical Distributions of Fish Passage within B1 Turbine Intakes in Spring and Summer 2005, after Standardizing Sampling Elevation. Percentages above elevation 31 ft were estimated from samples of up-looking hydroacoustic beams and those at or below elevation 31 were estimated from down-looking hydroacoustic beams. Figure from Ploskey et al. 2006c.

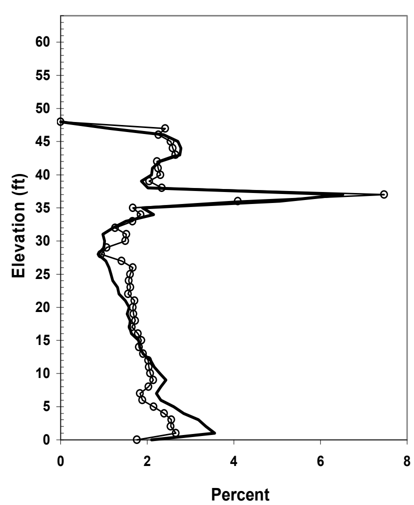

Figure 3.76. Average Vertical Distributions of Fish Passage within B1 Turbine Intakes in Spring and Summer 2002. Percentages above elevation 31 ft were estimated from samples of up-looking hydroacoustic beams and those at or below elevation 31 were estimated from down-looking hydroacoustic beams. Figure from Ploskey et al. 2003.

The percent of fish passage varied just 1-2% among 1-ft-depth strata in B2 turbines and exhibited only a slight decline with decreasing elevation in spring and summer 2005. In spring, the percent passage within 1-ft strata between the bottom and ceiling of the intakes ranged from 1.0% to 3.5% (Figure 3.77). Except for a single peak of 5.4% at Elevation 21 ft in summer, the same relatively narrow range in percent passage also was observed for all strata in summer (Figure 3.77).

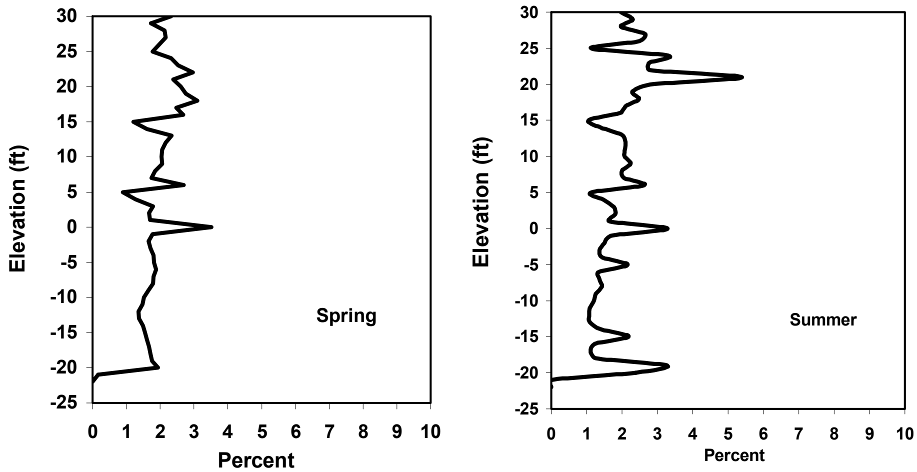

Figure 3.77. Vertical Distributions of Fish within B2 Turbine Intakes in Spring and Summer 2005

3.5.3.2 Spillway

The vertical distributions of fish passing the spillway in spring and summer were similar in 2004 and 2005 (Figure 3.78) and a peak occurred within 3 ft of the ogee at elevation 24 ft MSL (Ploskey et al. 2005). Spilling through more gates with smaller openings may have implications for survival as recent data suggest that passage near an ogee may increase the risk of injury or death (Thomas Carlson, PNNL, Personal Communication).

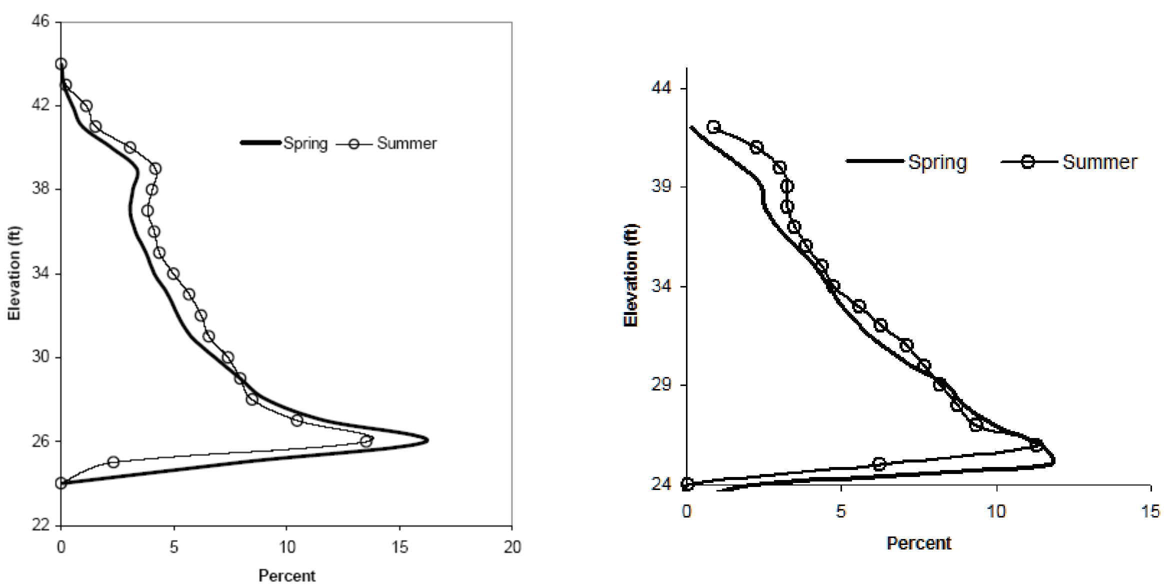

Figure 3.78. Vertical distributions of Fish Passage at Spillway in 2004 (Left) and 2005 (Right)

3.5.3.3 Deep Surface Flow Outlets – PSC and B2CC

A full evaluation of the Prototype Surface Collector (PSC) was undertaken in 2000 with results presented in Section 3.3 of this report as provided by Ploskey et al. (2002a and b), Evans et al. (2001a and b), and Johnson and Carlson (2001). The vertical distribution of fish in front of the PSC at Powerhouse 1 was conducive for successful surface collection with a deep slot configuration. Sample volumes 1 to 3 m upstream of the PSC detected 92% to 99% of fish in spring and from 85% to 96% in summer above the elevation of the PSC floor.

The coverage of split-beams across the entrance of the B2CC can be visualized by examining a composite plot of all fish detections within the beams in spring and summer (Figure 3.79).

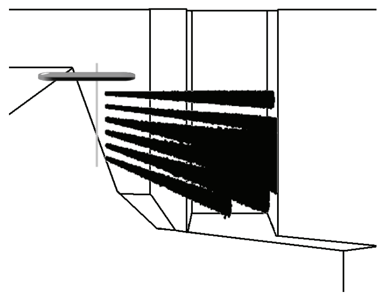

Figure 3.79. Plot of All Fish as Dots Where They were Detected within Acoustic Sample Volumes of Split-Beam Transducers to Illustrate Sampling Coverage at the B2CC Entrance in Spring and Summer, 2004. At low forebay elevations, the bottom two beams were truncated by the sill.

Fish passage at the B2CC was highly skewed toward the surface in both spring and summer (Figure 3.80). The percent of fish passing within 4 ft of the water surface was 63% in spring and 46% in summer. In summer, there was a noticeable peak in passage between the 15- and 20-ft depths, representing about 25% of the fish passing through the B2CC (Figure 3.80). The vertical distribution trend was similar during the day and night in both seasons, except for the peak in summer at 15 to 20 ft, which was only a daytime occurrence. When summer data collected after July 4 (when shad were running) are removed, the vertical distribution for summer is very similar to that observed in spring (Figure 3.81).

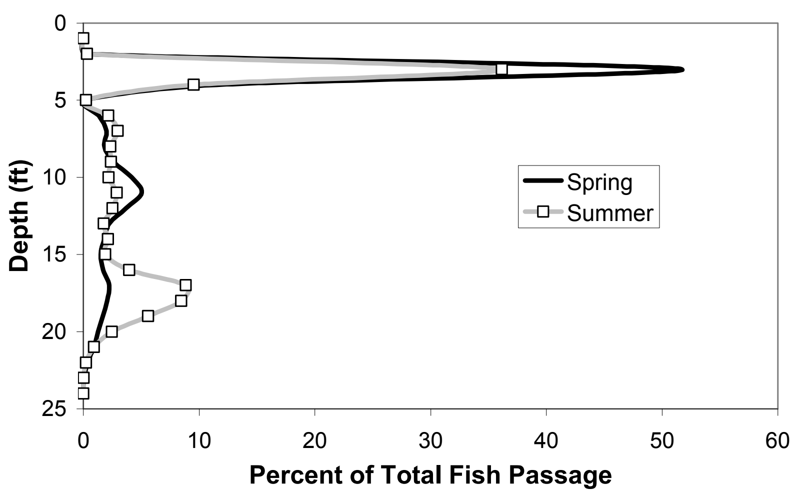

Figure 3.80. Vertical Distribution of Fish Passing through the B2CC in Spring and Summer 2004

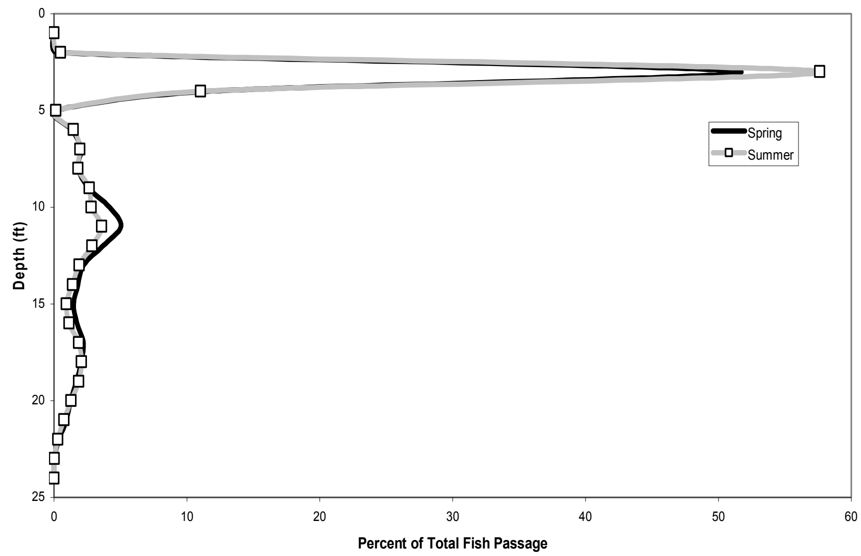

Figure 3.81. Vertical Distribution of Fish Passing through the B2CC in Spring and Summer through July 4, 2004, Only

In 2005, fish entering the B2CC were surface oriented in both seasons but were somewhat lower in the water column in summer than they were in spring (Figure 3.82). About 70% were detected in the top half of the opening (about 11 ft of depth) in spring, while only 60% were in the top half of the opening in summer.

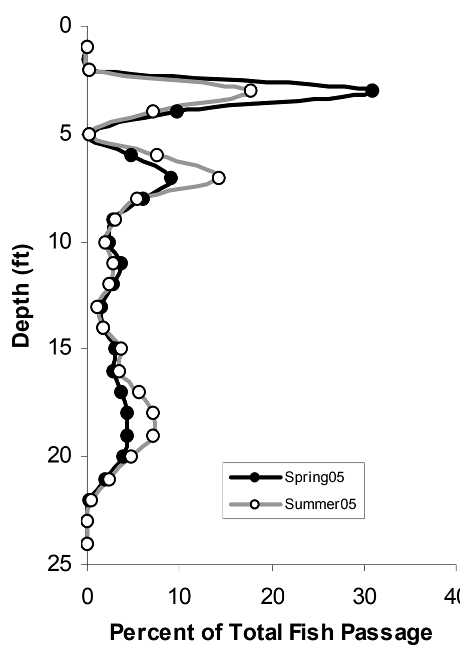

Figure 3.82. Vertical Distributions of Fish at the B2CC Entrance in 2005.

3.5.4 Diel Distributions

It is easiest to talk about diel distribution by type of passage route (turbines, spillway, and surface passage outlets) because trends are more apparent and consistent than they are by structure (B1, B2, and the spillway). However, it is very important to differentiate between diel patterns that are driven by diel shifts in project operations and discharge and natural patterns that occur when operations are relatively constant.

3.5.4.1 Turbines

When turbines run 24 hours per day, fish passage usually is crepuscular with peaks occurring after sunset and about dawn, and passage usually is higher at night than it is during the daytime. Some examples will help make this point. Willis and Uremovich (1981) found that 60% of juvenile salmonids passed Powerhouse 1 at night, in spite of the fact that 82% of the sluiceway-passage component occurred during the daytime. Mean hourly hydroacoustic estimates of smolt passage into turbine units 3 and 5 in 1996 generally were higher during night hours than during day hours for both the spring and summer (Figure 3.83). Another example from B1 is Unit 8 in 1998 (Figure 3.84). Abrupt peaks in passage around sunset are evident for fish guided by the extended submerged traveling screen in both spring and summer and for unguided fish in summer. Note that the onset of increased passage occurs 1-2 hours later in summer than it did in spring. These trends are not unlike what can be observed for juvenile bypass system (JBS) data except that there is a delay of several hours in the observed peaks for JBS data since fish may delay in gatewell slots (e.g., see Ploskey et al. 2000). When turbines dominate project operations, as they did in 2001, similar diel patterns can be observed for total project passage (Figure 3.85), but in general a single turbine running the same discharge 24 hours per day provides the best look at a typical diel pattern (e.g., B2 Turbine 18 in spring 2005 – Figure 3.86). At B2, turbines 11 and 18 had generation priority, and were most likely to run 24 hours per day.

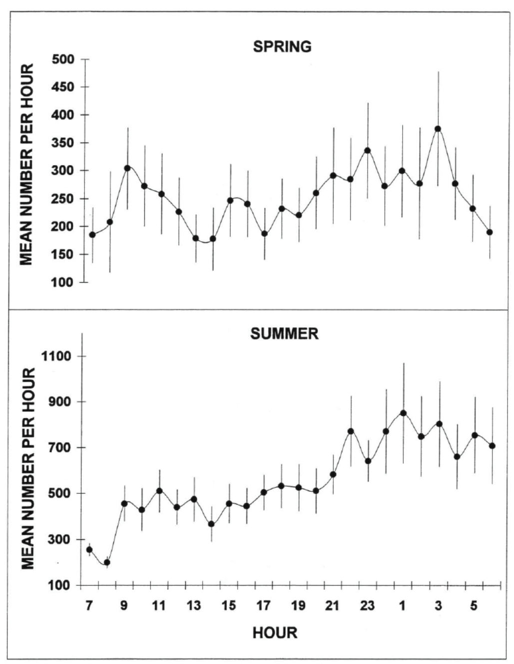

Figure 3.83. Diel Trend in Mean Hourly Passage in 1996 at Two B1 Turbines

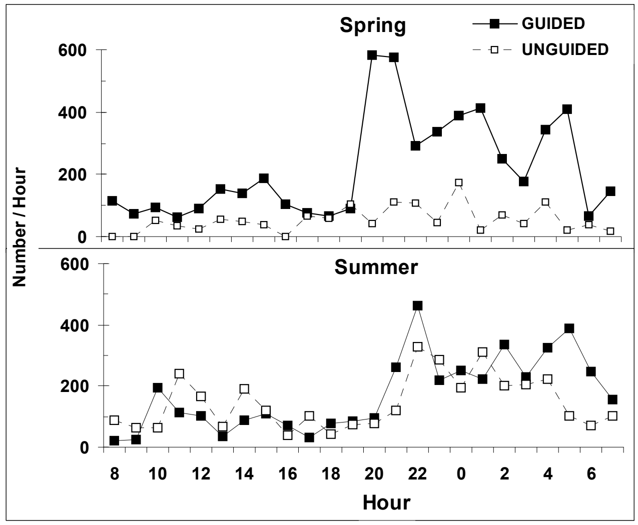

Figure 3.84. Diel Trends in Fish Passage Above (Guided) and Below (Unguided) an ESBS at Intake 8B in Spring and Summer 1998. Figure from Ploskey et al. 2001a.

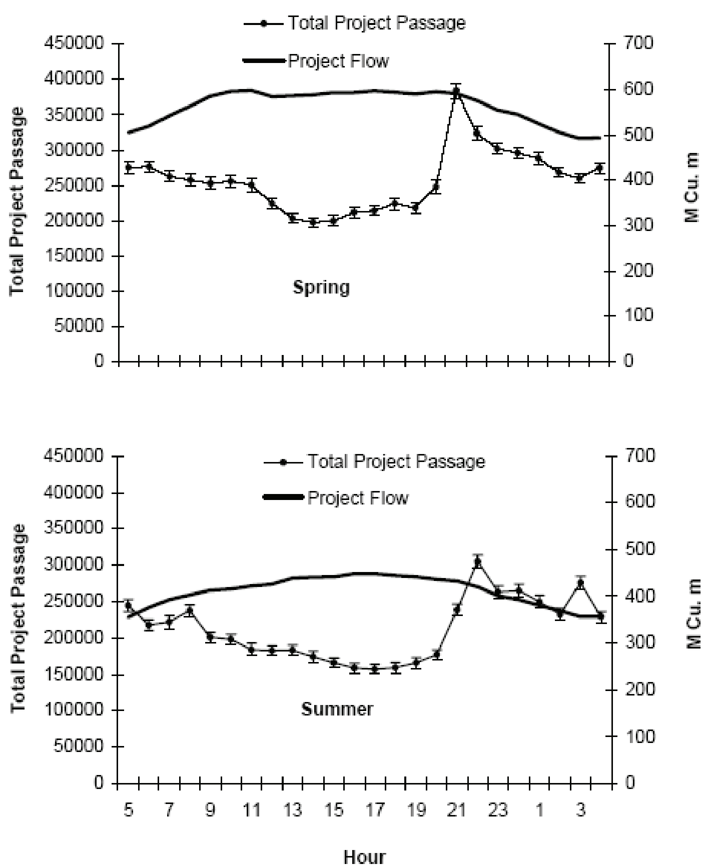

Figure 3.85. Diel Trends in Total Project Passage in 2001, when Spill Passage was Low Relative to Turbine Passage. Figure from Ploskey et al. 2002c.

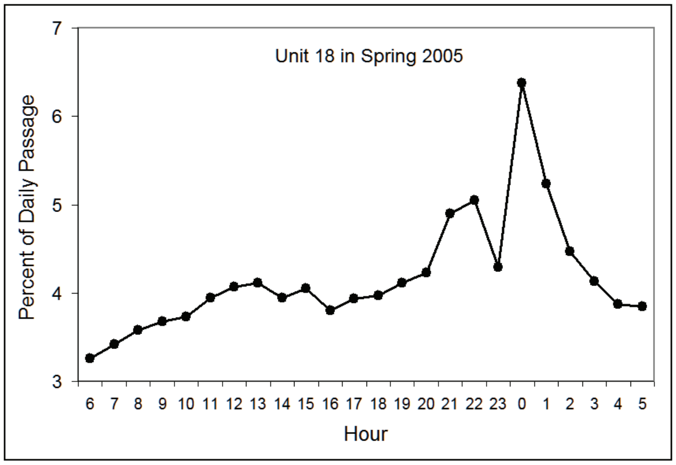

Figure 3.86. Average Diel Trend in Fish Passage through Turbine 18 in Spring 2005.

Turbine discharge and fish passage at B1 in spring and summer 2005 provide a good example of an atypical diel pattern driven by turbine operations (Figure 3.87; Ploskey et al. 2006c). In this example, turbine discharge controls passage, whereas in earlier examples for B1 turbines, the units ran 24 hours per day. Similar atypical examples were observed at B1 in 2004 (Ploskey et al. 2005). These diel patterns are of interest because they show the degree to which diel patterns can be altered by operations. Another atypical example of a diel trend for turbine passage was observed in B2 turbine passage in summer 2005, when most turbines between Unit 11 and 18 were shut down to provide water for increased spill at night (Figure 3.88). In both Figure 3.87 and 3.88, we would expect to see higher turbine passage at night than during the day if discharge had been constant, which it was not.

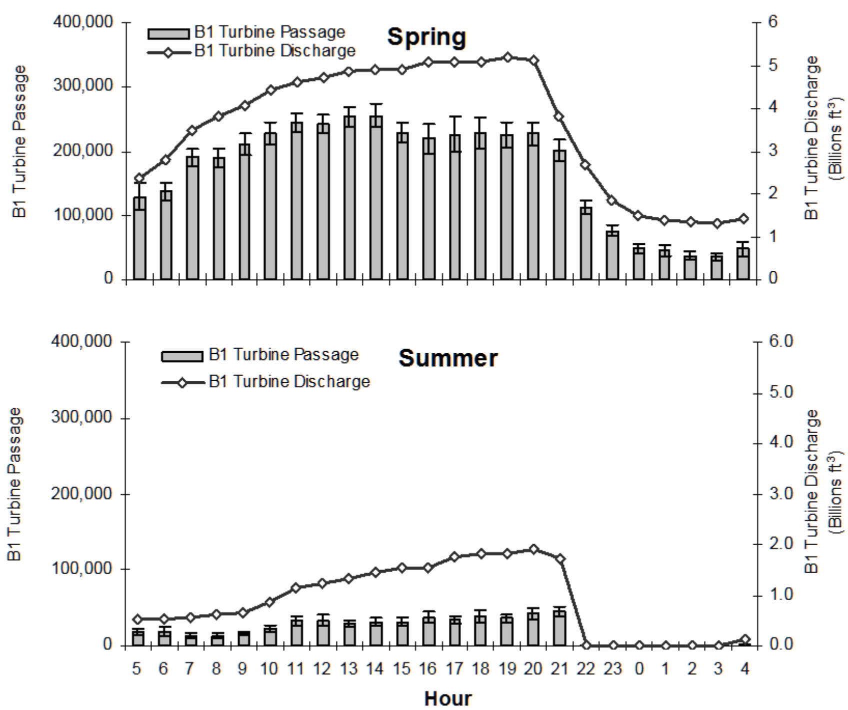

Figure 3.87. Diel Trends in Fish Passage Above (Guided) and Below (Unguided) an ESBS at Intake 8B in Spring and Summer 1998. Plots were taken from Ploskey et al. 2006c.

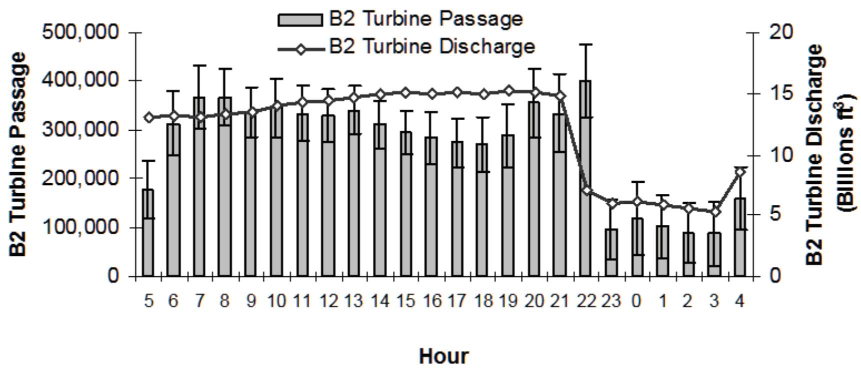

Figure 3.88. Diel Trends in Fish Passage in B2 Turbine Passage in Summer 2005. Plot was taken from Ploskey et al. 2006c.

3.5.4.2 Spillway

3.5.4.2.1 Hydroacoustics

Determining a natural diel pattern of passage at the Bonneville Dam spillway has been difficult because discharge usually is much higher at night than it is during the day, and spill passage efficiency is directly correlated with percent spill (Figures 3.2, 3.3, and 3.4). Typically, spill passage and spill efficiency increase significantly at night because discharge increases (e.g., Figure 3.89, 3.90, 3.91, 3.92).

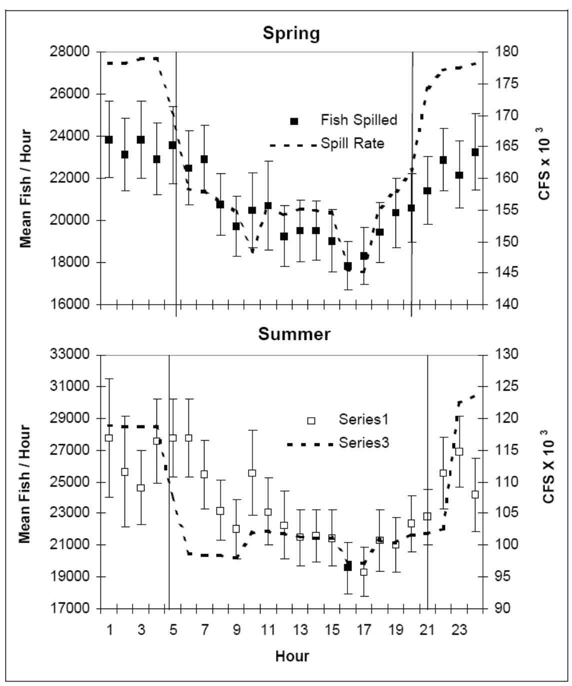

Figure 3.89. Hourly Patterns in the Mean Number of Fish Spilled per Hour in Spring and Summer 2000. Error bars represent 80% confidence limits about the mean. Vertical lines indicate average times of sunrise and sunset. Figure from Ploskey et al. 2002a.

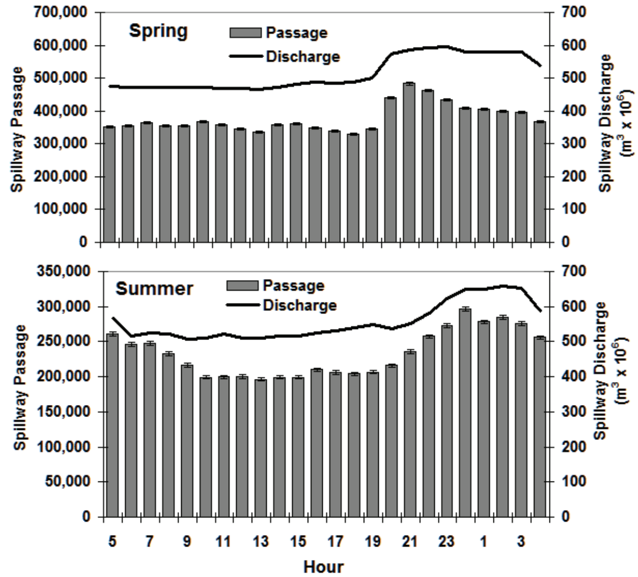

Figure 3.90. Estimates of Diel Trends in Spilled Fish and Spillway Discharge in Spring and Summer 2002. Note the scale of vertical passage (left) axis in spring extends to twice what it does in summer. Error bars represent 95% confidence intervals on fish passage estimates. Figure from Ploskey et al. 2003.

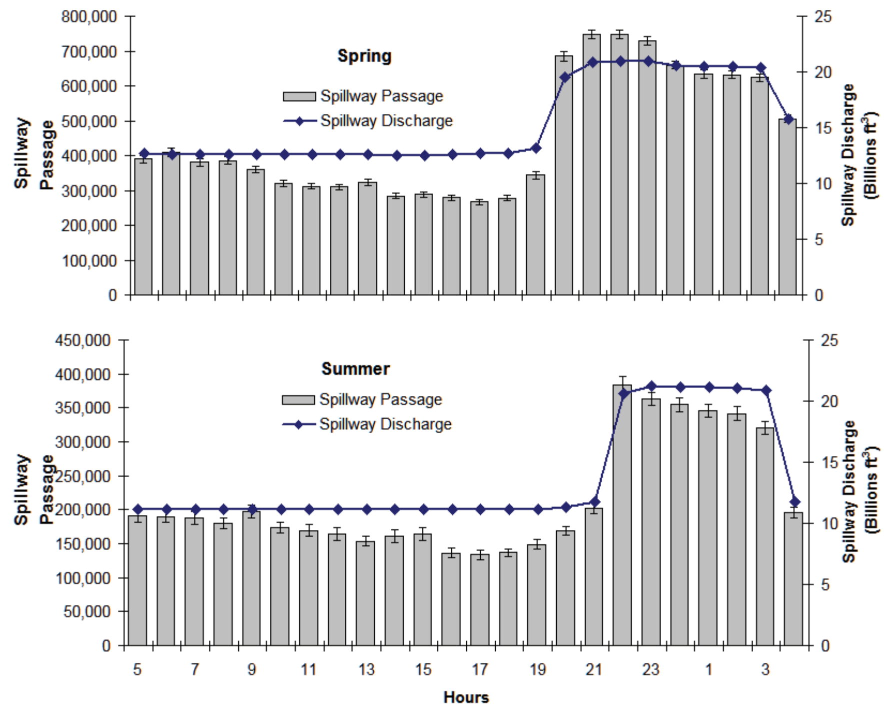

Figure 3.91. Estimated Hourly Spillway Passage and Discharge at Bonneville Dam in Spring and Summer of 2004. Error bars represent 95% confidence limits on fish passage estimates. From Ploskey et al. 2005.

There have only been a few times when spill was held constant and a natural diel pattern, independent of discharge, could be observed. In the drought year of 2001, when spill was nearly constant 24 hours per day, Ploskey et al. (2002c) described diel trends with a decline during daylight hours and an increase at

2100 hours in spring and 2200 hours in summer (Figure 3.93). In 2004, there were six days in summer when spill was deliberately held constant for 24 hours, and these conditions again afforded researchers the opportunity to examine diel patterns of spill passage independent of discharge (Figure 3.94). The patterns in Figures 3.93 and 3.94 clearly indicate that the diel patterns observed in Figures 3.89 through 3.92 are not entirely due to increased discharge at night.

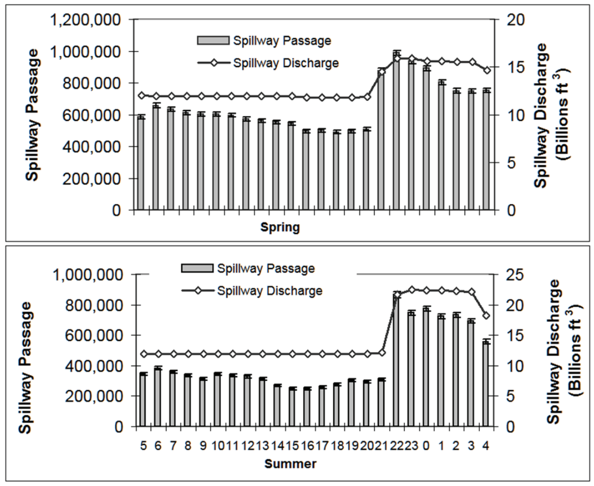

Figure 3.92. Estimated Hourly Spillway Passage and Discharge at Bonneville Dam in Spring and Summer of 2005. Error bars represent 95% confidence limits on fish passage estimates. From Ploskey et al. 2006c.

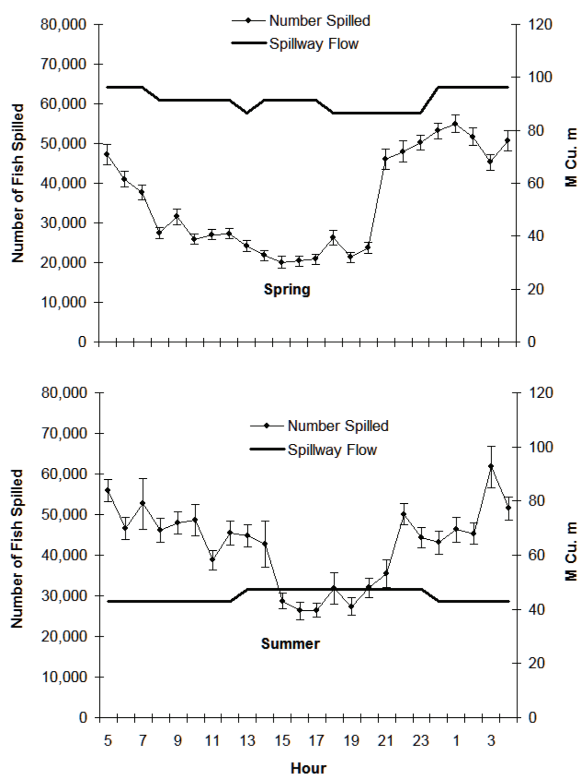

Figure 3.93. Estimates of Diel Trends in Spillway Fish Passage and Spillway Discharge in Spring And Summer 2001 Under Nearly Constant Spill. Error bars represent 95% confidence intervals. Figure from Ploskey et al. 2002c.

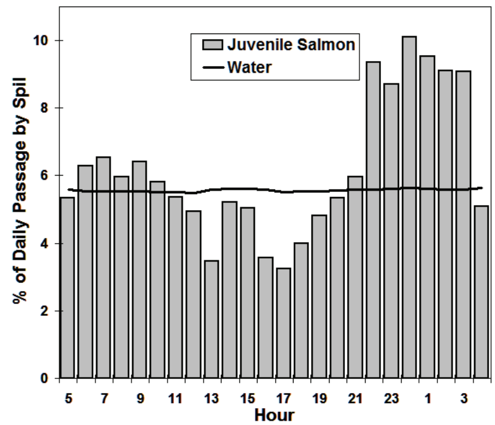

Figure 3.94. Estimated Hourly Spillway Passage and Discharge at Bonneville Dam during Six Days in Summer 2004. From Ploskey et al. 2005.

3.5.4.2.2 Radio Telemetry

With the exception of yearling Chinook salmon in 2000, all species passed the spillway at a higher hourly rate at night than during the day in studies conducted from 2000 through 2002. All but one radio-telemetry result in 2004 and 2005 indicated that spillway passage rates were higher at night than they were during the day (Table 3.24). Prior to 2001, diel passage trends based on radio-tagged fish were only reported on a project-wide basis; therefore, structure-specific diel patterns are not available for those years (Holmberg et al. 1996; Hensleigh et al. 1999; Hansel et al. 1999; Plumb et al. 2001). Spillway passage of yearling Chinook salmon in 2001 indicated a diel pattern characterized by a primary mode of passage peaking at 0700 hr and a secondary mode peaking at 1600 hr (Evans et al. 2001c). Only 11 subyearling Chinook salmon passed the spillway in 2001, resulting in an uninformative diel picture of passage (Evans et al. 2001d). Other than day/night differences in passage through the spillway in 2000 and 2002, hourly passage patterns were not reported for the different structures at Bonneville Dam for those years.

Table 3.24. Radio Telemetry Rates of Spillway Passage during the Day and at Night

Year	Tagged Fish	Spill Treatment	Spillway Passage Rate		Reference
			Night	Day	
2004	Yearling Chinook		2.8	1.7	Reagan et al.
2005	Yearling Chinook		2.9	1.7	Adams et al.
2004	Steelhead		2.2	0.5	Reagan et al.
2005	Steelhead		3.4	0.7	Adams et al.
2004	Subyearling Chinook	Overall	3.5	3.1	Evans et al.
2004	Subyearling Chinook	Biop Spill	5.7	2.9	Evans et al.
2004	Subyearling Chinook	37 kcfs spill	1.6	2.1	Evans et al.
2005	Subyearling Chinook	Overall	3.1	2.7	Adams et al.

3.5.4.3 Surface Flow Outlets

Most research indicates that a majority of fish pass surface-flow outlets during daylight hours, unlike passage through turbines and the spillway, as described above. The only exceptions that we found were based upon early video camera and hydroacoustic estimates for the B1 sluiceway (Ploskey et al. 1998) and for PSC slots in 1998 (Ploskey et al. 2001a) and for the 5-ft-wide PSC slot in 1999 (Ploskey et al. 2001b). These data were collected before detectability effects of turbulence and light on video samples and of water velocity on fish movement were considered or addressed. Most hydroacoustic estimates for the B1 sluiceway before 2002 were based on samples upstream of the sill and included very few entrained fish. Therefore, those estimates were not reliable because uncommitted fish could be detected more than once. We suspect that is why some hydroacoustic estimates for fish detected upstream of PSC slots in 1998 appeared to be higher at night than they were during the day (Ploskey et al. 2001b). Recent DIDSON video clips (Ploskey et al. 2006c) show that smolts hold in loose schools upstream of the B1 sluiceway at night and are more hesitant to enter the B1 sluiceway at night than they are during the day. If the same hesitation to enter upstream of the 5-ft-wide-PSC slot at night would lead to multiple counting that would be less likely to occur during the day.

3.5.4.3.1 B1 Sluiceway

Willis and Uremovich (1981) fished a fyke net in the B1 sluiceway outlet at Unit 1 and found that 82% of all yearling salmonids passed during the day between 1700 and 1900 hours. They presented diel plots for yearling Chinook salmon, coho, steelhead, and sockeye, and each plot indicated predominant passage during daylight hours. The very first reliable hydroacoustic estimates of passage into the B1 sluiceway were reported in 2004 (Figure 3.95) and 2005 (Figure 3.96), and both show higher passage during the day than at night.

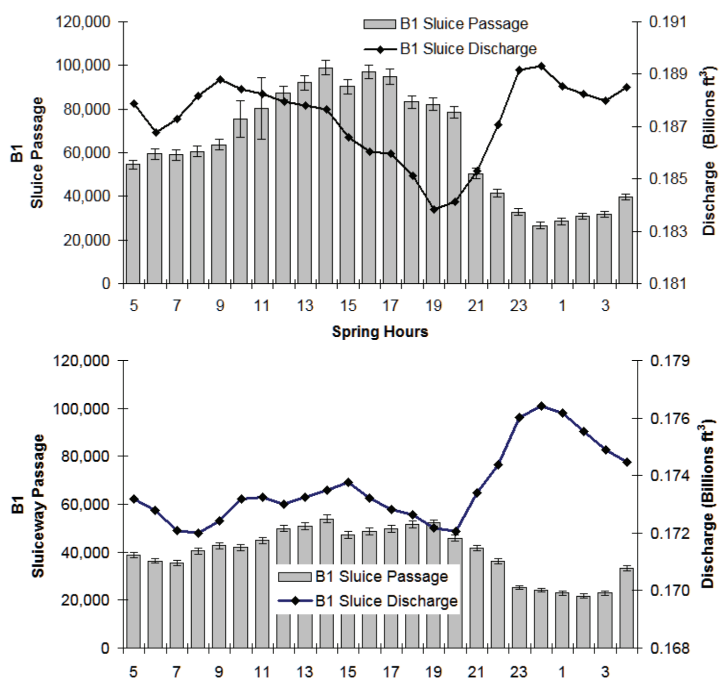

Figure 3.95. Diel Trends in B1 Sluiceway Passage in Spring (Top) and Summer (Bottom) 2004. Plots were adapted from Ploskey et al. 2005.

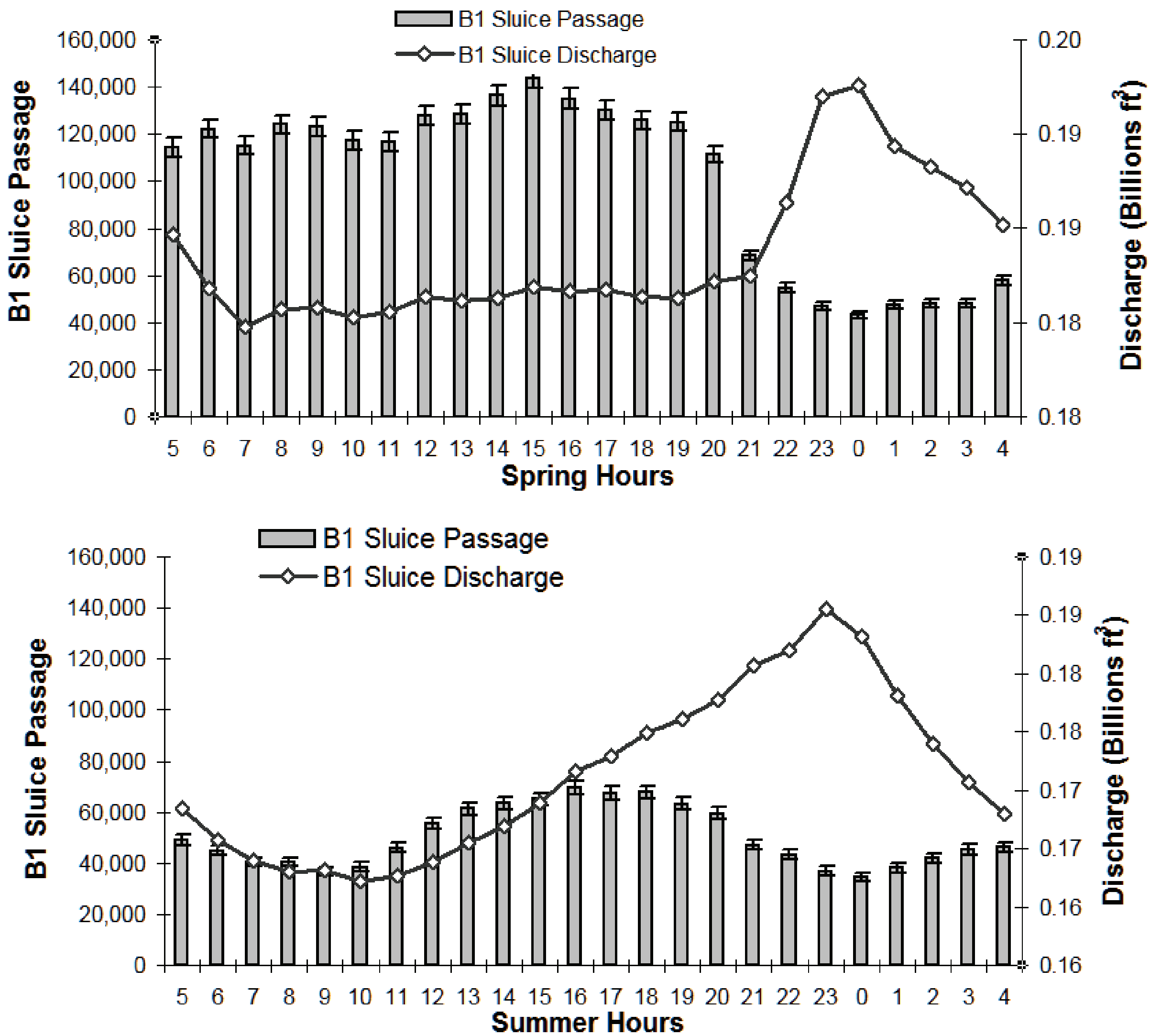

Figure 3.96. Diel Trends in B1 Sluiceway Passage in Spring (Top) and Summer (Bottom) 2005. Plots were adapted from Ploskey et al. 2006c.

3.5.4.3.2 Prototype Surface Collector

Hydroacoustic data from 1998 and 2000 indicated that detections of fish upstream of the 20-ft-wide PSC slots were much higher during the day than they were at night (Figure 3.97 and 3.98), although this was not true for detections upstream of the 5-ft wide slot, for unknown reasons. These data undoubtedly were subject to bias because fish were not entrained when detected. However, Evans et al. (2001a) also reported that most steelhead and yearling Chinook salmon entered the 20-ft-wide entrance slot during the day (Figure 3.99). Sixty-nine percent of steelhead entered the PSC during daylight hours, and passage of steelhead into the PSC peaked during the crepuscular period. Likewise, 83% of Chinook salmon entered the PSC during daylight hours. Passage of yearling Chinook salmon into the PSC peaked during midday. Evans et al. (2001b) reported that 85% of subyearling Chinook salmon entered the PSC during the day.

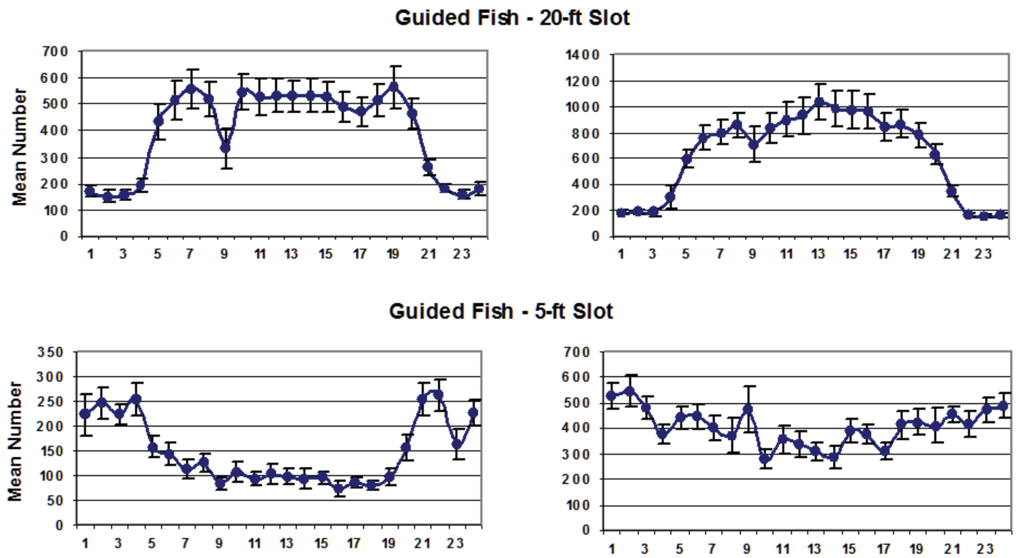

Figure 3.97. Estimated Mean Hourly Passage into the 20-ft and 5-ft Wide Slots in the PSC in 1998 (from `Ploskey et al. 2001a).

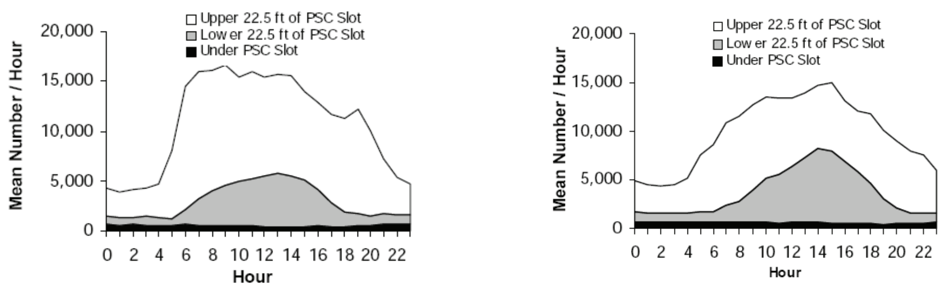

Figure 3.98. Estimated Mean Hourly Passage into the 20-ft Wide Slot in the PSC in 2000 (from Ploskey et al. 2002b).

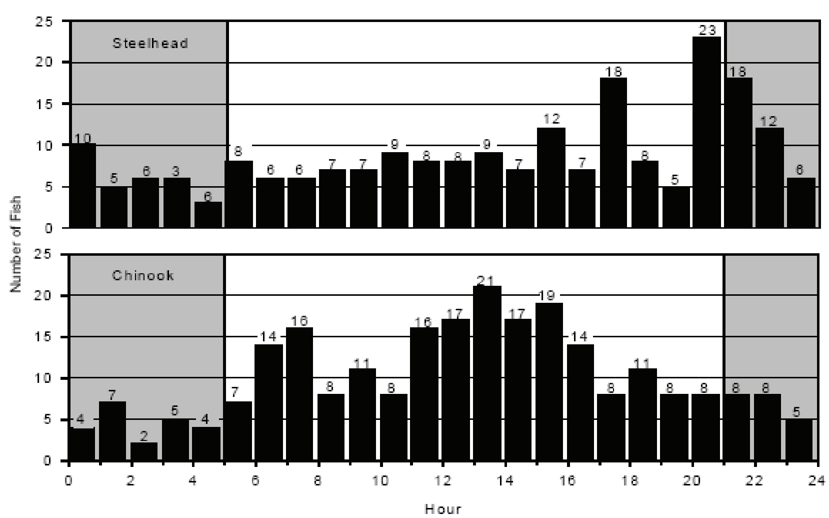

Figure 3.99. Number of Steelhead and Yearling Chinook Salmon that Entered the PSC by Hour of Day during Spring 2000. From Evans et al. 2001a.

3.5.4.3.3 B2 Sluice Chute / B2CC

Like other surface passage routes at Bonneville Dam, the B2 sluiceway outlet (B2 sluice chute before 2004 and B2CC thereafter) has a daytime dominated diel pattern of fish passage. The first reported diel passage data for Bonneville Dam was that of Magne et al. (1986), who noted that sluice chute passage in 1986 during the period June 11-14 was highest during daylight hours as compared to hours of darkness. However, Magne et al. (1986) stated that this trend might have been influenced by operations since B2 was only operated from 0700-2000 hr during the period of sampling. In 1997, fish passing the sluice chute exhibited a peak in passage during the day between 0800 and 1100 hours in the spring with a secondary mode between 1800 and 2100 hours (BioSonics 1998). During summer 1997, passage was characterized by a morning primary peak between 0600 and 0900 hours, and the fewest fish passed between 2100 and 2200 hours (BioSonics 1998). Diel patterns of sluice chute passage in 1998 were characterized by higher counts during the day and considerably fewer fish passing at night during spring and summer (Figure 3.100). In 2004 and 2005, the diel patterns of the B2CC continued to have higher passage during the day than at night (Figure 3.101; Ploskey et al. 2005, 2006c).

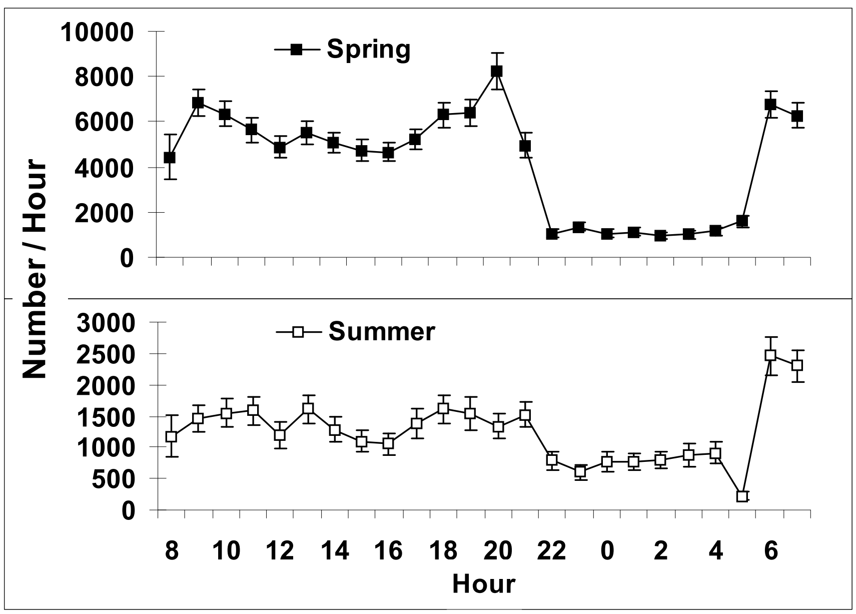

Figure 3.100. Diel Trends in Hourly Passage of Fish through the Sluice Chute at B2 in Spring and Summer 1998. Note the vertical scale for spring is three times greater than for summer. Error bars denote 95% confidence intervals on estimates. Figure from Ploskey et al. 2001a.

3.5.5 Synthesis and Conclusions

After reviewing the body of work conducted over the last 20 years assessing the distribution of fish passage at Bonneville Dam, we offer the following synthesis and conclusions.

3.5.5.1 Horizontal Distributions

The proportion of fish passage through B1, the spillway, and B2 was nearly proportional to discharge at each location. This observation was consistent throughout five years of full-project-passage assessment based upon both radio telemetry and hydroacoustic techniques.

Distributions of fish associated with passage through various routes within B1, the spillway, and B2 depend on discharge in that fish cannot pass through routes that are closed. This is why patterns of fish passage through B1 turbines varied a lot after the powerhouse priority was shifted to B2 in 2001 and thereafter. Different units were running in different years depending upon unit priority and outages for retrofitting or maintenance. The general correspondence between fish passage and discharge can be seen in parts of Figures 3.54 and 3.56, although exceptions are there as well (e.g., bays 1-4 in Figure 3.54).

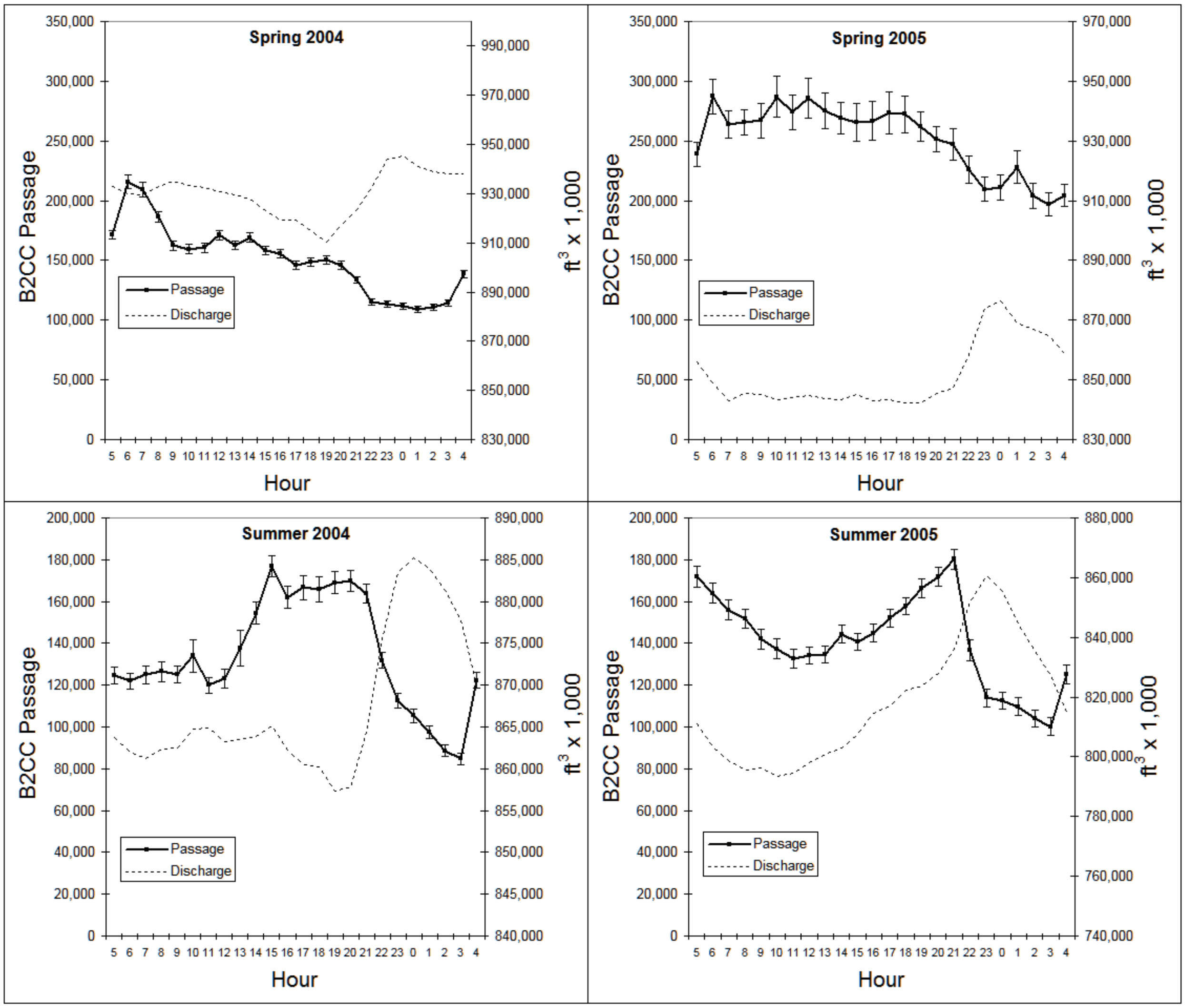

Figure 3.101. Diel Trends in Hourly Passage of Fish through the B2CC in Spring and Summer of 2004 and 2005. Error bars denote 95% confidence intervals on estimates. Figure adapted from data in Ploskey et al. 2005, 2006c.

Horizontal distributions should always be plotted with route-specific discharge and interpreted in that context, something that was not always done in reports before 2004. The addition of discharge to distribution plots allows readers to get a sense of whether or not distributions were driven by project operations. Without plotting or considering the route-specific distribution of discharge, one might conclude that the fish passage distribution across B1 from 1996 to 2002 were simply not uniform or consistent. Distributions of passage varied across years and seasons, with units north of the wing wall passing the majority of fish in some years (e.g., in 1996, Holmberg et al. 1996, and 2001, Ploskey et al. 2002c, and units south of the wing wall passing the most fish in other years, e.g., in 2000, Evans et al. (2001a, b).

However, the general relation between discharge and passage breaks down for surface flow outlets, because juvenile salmonids apparently preferentially select these surface routes over other, deeper routes. This selection leads to high measures of effectiveness (high efficiency with low water proportions). This is very evident in plots of the fish density of passage by route (Figures 3.52, 3.55, and 3.57). Surface passage routes have much higher efficiency at low flow proportions than do either the spillway or turbines (Figure 3.13).

Like the sluiceway at B1, the B2CC is a highly effective route of passage, clearly passing many more fish than any turbine unit and exponentially more on the basis of fish per unit of discharge. Lateral passage into the B2CC is not uniform. A majority of fish pass in the middle relative to the north and south sides, at least near the water's surface, where most fish are distributed. Intake piers from units 11 through 13 shed vortices and create turbulence that has an unknown effect on B2CC performance. Spare trash racks with plywood blocks on the upstream surfaces could be dropped into trash-rack slots in units 11 and 12 on top of existing trash racks to reduce shedding of turbulent flow. The blocked racks would act as cheap fillers for the space between piers and could be put in and removed to create treatments that could be evaluated. The turbulence shed from piers tends to push flow away from the powerhouse face, and this could increase passage of fish into the north eddy instead of into the B2CC.

Non-uniformity of passage across openings to surface flow outlets was typical. Distributions of fish passing over chain gates at B1 sluiceway outlets sometimes favored the middle and sometimes edges near piers according to video camera counts and later according to hydroacoustic counts after hydroacoustic sampling became reliable (after 2001). Acoustic camera (DIDSON) images of fish entering these outlets reveal a dynamic seemingly unpredictable process mediated by time of day, vortices to the turbine below the opening, and other hydraulic characteristics, as well as the original direction of approach by fish (Ploskey et al. 2006c). The same was true for the lateral distribution of fish entering the PSC and the B2CC, where lateral distribution sometimes varied with depth.

The distribution of fish passage among bays with different spill deflector types may be more important than north or south skews in spillway passage distributions, both of which have been reported. Survival data suggest that fish passing through bays with older 14-ft-elevation deflectors may have lower survival than fish passing through bays with the new 7-ft-elevation deflectors (Counihan et al. 2003, 2006a). If passage among bays were uniform, we would expect 67% of fish to pass through bays with the older, apparently less fish-friendly deflectors. However, 2004 and 2005 operations apparently reduced the percentage passing through bays 4-15 by 6-9% from what would be expected. Hydroacoustic data indicated that 57%-60% of fish passage was through bays 4-15 instead of 67%. Since discharge patterns appear to be partially responsible for trends in spillway passage distributions (see Figure 3.54 and 3.56), some tweaking of discharge to reduce the percent passing through bays with old spill deflectors may be warranted. Spill patterns were changed in 2002, and new patterns spill slightly more on the ends than in the middle of the spillway, and this apparently slightly favors passing fish through bays with 7-ft elevation deflectors.

Numbers of radio tagged fish detected at the spillway each season between 1996 and 1999 were only sufficient to provide a broad description of passage trends by north and south halves of the structure, and estimates in later studies were reported only as a proportion of total project passage. At best, skews in spillway passage distributions could be described as weak in most years, with just over 50% to 65% of fish favoring one half of the spillway or the other.

Almost all hydroacoustic and radio telemetry studies reflect a strong skew toward the south end of the powerhouse. With very few exceptions across season, year, or methodology, units 11-14 (especially units 11 and 12) passed the majority of fish as compared to units 15-18 on the north half of B2. As with lateral fish passage across intakes at B1, distributions across turbine intakes at B2 were not uniform. Leaving TIEs out from unit 11 through 14 undoubtedly facilitates a strong southerly flow of water along the powerhouse face toward the B2CC, and this is highly desirable for increasing fish passage at the B2CC. The TIEs retained on every other intake from Intake 15A through 18B help break up the flow toward the north eddy and likely increase passage and FGE at intakes between TIEs.

Turbine-intake extensions have created some predictable patterns in passage among intakes at B2, although horizontal distributions across intakes of the same turbine typically were not uniform or predictable based on hydroacoustic sampling at B1. Discharge through Bonneville Dam turbines typically is highest at the south (A) intake, intermediate at the middle (B) intake, and lowest at the north (C) intake, but passage seldom follows the discharge pattern. Hydroacoustic data have sometimes shown about 10% higher passage through intakes between TIEs than intakes behind TIEs at B2 (e.g., Ploskey et al. 2002c; Ploskey et al. 2003). In 2002, the B and C slots of B2 units and those intakes between TIEs at B2 had significantly higher FGE than did A slots or intakes behind TIEs, respectively. This probably is because two adjacent TIEs create vortices between them, and vortices funnel fish down the face of the dam where they enter high in the intake and are easily guided. In 2002, the B slot of Unit 17 had a higher FGE than did the C slot, and this likely was because the B slot was between two TIEs. Monk et al. (1999b) noted that FGE for yearling Chinook salmon increased 20% for intakes between TIEs.

3.5.5.2 Vertical Distributions

A number of investigators have assessed the vertical distribution of fish upstream of passage structures, but those data do not accurately reflect distributions of fish committed to passage. About 100 ft upstream of trash racks at B2, fish were distributed very high in the water column, and those distributions seemed contrary with low in-turbine estimates of FGE (Ploskey et al. 2002a) but were fairly consistent with vertical distribution estimates for the B2CC (Ploskey et al. 2005, 2006c). Fish upstream of the PSC and immediately upstream of B2 trash racks were less highly skewed toward the water's surface (Ploskey et al. 2002a and 2002c).

The vertical distribution at surface flow outlets first depends upon the depth of the outlet. The B1 sluiceway is very shallow and yet highly efficient, consistently passing over 33% of B1 fish passage, when B1 is not the priority powerhouse. When the 40-45 ft deep PSC took fish at all depths although slightly more entered in the upper half than the lower half, and the PSC also was highly efficient and effective. Given that the vertical distribution of fish in B1 turbines is not skewed toward the top of the intake and fish occur a many depths, the depth of the PSC was not wasted. At the PSC, entrance depths varied by species and time of day according to radio telemetry. The vertical distribution of passage at the

B2CC is highly skewed toward the surface of the water, even though about 24 ft of depth is available for passage.

At the spillway, the vertical distribution of passage peaks within a few feet above the elevation of the ogee crest, and this could be undesirable in terms of survival. Fish passing deep and close to the ogee sometimes experience higher incidence of injury and mortality than fish passing from higher in the water column (Thomas Carlson, Personal Communication).

In-turbine distributions at both B1 and B2 are not highly skewed toward higher elevations as they often are at upstream hydropower projects. There also is evidence of a skew toward both higher and lower elevations at B1 intakes, especially in summer (e.g., Ploskey et al. 2002c). In-turbine vertical distribution data are generally consistent with FGE estimates that are 50% or less.

3.5.5.3 Diel Distributions

It is easiest to talk about diel distribution by type of passage route (turbines, spillway, and surface passage outlets) because trends are more apparent and consistent than they are by structure (B1, B2, and the spillway). However, it is very important to differentiate between diel patterns that are driven by diel shifts in project operations and discharge and natural patterns that occur when operations are relatively constant.

The diel patterns of passage through turbines and the spillway suggest that some fish may be holding in forebay areas during the day and passing at night, although short radio telemetry residence times suggest that holding cannot be prolonged (a few hours at most). Nevertheless, the crepuscular peaks in passage in bypass systems, fyke net samples, and hydroacoustic samples would only result if some delay occurred. The loss of visual position cues may be responsible for increased fish passage into turbines just after sunset because smolt passage at turbine units is not a function of increased flow at that time.

3.5.5.3.1 Turbines

When turbines run 24 hours per day, fish passage usually is crepuscular with peaks occurring after sunset and about dawn, and passage usually is higher at night than it is during the daytime. These trends are not unlike what can be observed for JBS data except that there is a delay of several hours in the observed peaks for JBS data since fish may delay in gatewell slots. When turbines dominate project operations, as they did in 2001, similar diel patterns can be observed for total project passage, but in general a single turbine running the same discharge 24 hours per day provides the best look at a typical diel pattern.

Atypical diel patterns of passage at turbines result from turbines not running consistently over a diel cycle, so it is important to show discharge on diel plots, if turbine operations are unknown. Turbine discharge and fish passage at B1 in spring and summer 2005 provide a good example of an atypical diel pattern driven by turbine operations (Figure 3.87; Ploskey et al. 2006c). These diel patterns are of interest because they show the degree to which diel patterns can be altered by operations. Another atypical example of a diel trend for turbine passage was observed in B2 turbine passage in summer 2005, when most turbines between units 11 and 18 were shut down to provide water for increased spill at night.

3.5.5.3.2 Spillway

In a couple of cases when discharge was held constant throughout 24-hour periods (e.g., during the drought of 2001 and for six days in summer 2004), hourly passage estimates clearly indicate that nighttime-dominated diel patterns are not entirely due to increased discharge at night. In the drought year of 2001, when spill was nearly constant 24 hours per day, Ploskey et al. (2002c) described diel trends with a decline during daylight hours, an increase at 2100 hours in spring and 2200 hours in summer (Figure 3.93). Except for those periods of constant discharge for 24 hours, separating a natural diel pattern of passage at the Bonneville Dam spillway has been difficult because discharge usually is much higher at night and spill efficiency is directly correlated with discharge. With the exception of yearling Chinook salmon in 2000, all other studies of radio-tagged fish showed higher hourly rates of spillway passage at night than during the day.

3.5.5.3.3 Surface Flow Outlets

Most research indicates that a majority of fish pass surface flow outlets during daylight hours, unlike passage through turbines and the spillway described above. Netting data by Willis and Uremovich (1981), hydroacoustic data collected after 2001, and DIDSON video clips all indicate that B1 sluiceway passage is higher at night than it was during the day. Results for the 20-ft-wide slot at the PSC showed higher passage at night than during the day based upon hydroacoustic sampling (Ploskey et al. 2001b, 2002a and b) and radio telemetry sampling (Evans et al. 2001a; Evans et al. 2001b). The B2 sluiceway outlet (B2 sluice chute before 2004 and B2CC thereafter) had a daytime-dominated diel pattern of fish passage (Magne et al. 1886; BioSonics 1998; Ploskey et al. 2001a; Ploskey et al. 2005, 2006c).

The predominance of fish passage through surface routes during the day indicates that smolts are readily entering those outlets, but DIDSON video indicates that smolts often are holding upstream of outlets at night. Day and night DIDSON recordings of smolt behavior upstream of the B1 sluiceway in 2005 (Ploskey et al. 2006c) certainly support the nighttime holding hypothesis for that location. Not only were smolts holding in large, loose schools at night, they were subjected to intensive predation, whereas during the daytime, tight schools of smolts readily entered B1 Sluiceway Outlet 3C and predation events were relatively rare. Similar recordings showing increased holding and predation at night in the south eddy upstream of the B2CC were recorded in 2004.

4.0 Survival

4.1 Dam and Project Survival

Shortly after the Bonneville Dam first powerhouse (B1) and spillway were built, efforts were initiated to estimate the passage effects on downstream migrating salmon. Holmes (1952) analyzed data collected during a series of experiments conducted between 1939 and 1945. In two of those years, treatment fish were released about five miles upstream from the dam, from either the Washington or Oregon shores in different years. Control groups were released in either the powerhouse tailrace or spillway tailrace in different years. Survival from release sites to the tailrace of the dam was estimated from adult recoveries of fin-clipped fish at hatcheries and fisheries (Table 4.1). Mortality passing the dam was estimated at 11% to 15% (85%-89% survival), depending on the analytical method Holmes (1952) applied, and was also likely influenced by the mix of release and control sites used in the different study years.

Not until 1999 was there another attempt to empirically estimate smolt survival passing the dam as a unit. Using radio-tagged yearling Chinook salmon, Counihan et al. (2002a) estimated survival from the face of the dam to the control release site below the new B2 JBS outfall at 96%. However, they cautioned that their estimate may be biased high. They noted that independent tests revealed some known dead fish bearing active tags that were intentionally released in the tailrace were subsequently detected at the detection arrays downstream. Detection of those fish indicated that one of the primary assumptions of the survival model had been violated.

In 2001, Counihan et al. (2002b) again used miniaturized radio tags to estimate smolt survival from Hood River, Oregon, to the tailrace of Bonneville Dam below the JBS outfall. Mean survival was estimated as 0.937 (S.E. = 0.014) and 0.902 (S.E. = 0.036) for yearling and subyearling Chinook salmon, respectively. These estimates reflect total effects incurred during passage. Overall, subyearling Chinook salmon survived at lower rates than yearlings. This is consistent with observations from other dams. As a cautionary note, these estimates reflect survival through only a portion of the entire hydroelectric project, since fish were released at Hood River and not the tailrace of The Dalles Dam. Also, the point estimates reported in this document (July 10, 2002; Final Draft) likely over-estimate the actual survival. As in the previous year, they observed that 1 of 30 known dead tagged fish of each species were detected at the downstream detection sites (i.e., false positive detections were verified).

In 2002 (Counihan et al. 2003) found that survival of yearling Chinook salmon passing the dam was the highest observed to date. Estimated survival from the face of the dam to the location of the JBS outfall was 0.977 (S.E. = 0.019). Unlike previous years, no known dead tagged fish were observed at downstream transects. Also, this was the first year they used a double detection array at the dam to yield a Lincoln Index for use in estimation models.

In 2004 and 2005, species coverage was broader (Table 4.1). Estimates of dam survival were generally high during these years, ranging from 93.8% to -99.1% across all species. Whether these should be treated as absolute estimates is uncertain. But given difficulties observed with false positives in previous years, it would be more conservative to use them as relative estimates.

Table 4.1. Smolt Survival Passing Bonneville Dam, or Partial-Project Survival (Part of the Pool and Dam). In some cases, partial-project estimates were calculated and noted in the table. These all reflect total effects.

Year	Species	% Survival (SE)	Coverage	Investigators
1939-1945	Fall Chinook	85-89	5 miles upstream to tailrace[1]	Holmes (1952)
2000	Yearling Chinook	96.0	Face of dam to below JBS outfall	Counihan et al. (2002a)
2001	Yearling Chinook	93.7(1.4)	Hood River, OR to JBS outfall	Counihan et al. (2002b)
2001	Subyearling Chinook	90.2(3.6)	Hood River, OR to JBS outfall	Counihan et al. (2002b)
2002	Yearling Chinook	97.7(1.9)	Face of dam to JBS outfall	Counihan et al. (2003)
2004	Yearling. Chinook	95.1(0.8)	`` ``	Counihan et al. (2006a)
	Steelhead	99.1(0.8)	`` ``	`` ``
2005	Yearling Chinook	96.6(0.7)	`` ``	Counihan et al. (2006b)
	Steelhead	96.3(0.7)	`` ``	`` ``
	Sub. Chinook	93.8(0.7)	`` ``	`` ``

[1] Treatment fish were released on the OR and WA shore in two different years. Control fish were released in either Powerhouse or spillway tailraces in different years several hundred yards downstream from the structure.

The telemetry-based survival estimates from the modern era (2000-2005) are all higher than survival estimates reported during the 1940s. This may not be surprising since numerous passage improvements in the form of bypasses and plant operations have been tested and adopted over the decades. Additionally, the estimates of Holmes (1952) include any delayed passage effects that might have existed and not been expressed until later in life. Even so, at least some of the dam survival estimates reported for the modern era may overstate passage survival to some extent because, in some years, dead fish bearing active tags were detected at downstream detection arrays. If radio-telemetry or any active tag methodology is to be accepted as producing an accurate measure of absolute survival, then new downstream detection sites should be established that avert this problem. Alternatively, perhaps a correction factor for false positives can be incorporated into the analytical method. In any event, dam or project survival estimates recently reported for this site may be biased slightly high.

The differences in survival estimates among years could be in part attributable to dam operations. In the drought year of 2001, the percent of water spilled (16%) was far below levels that occurred in other years like 2000 (32%) and 2002 (47%). Later in this document we explore how spill operations can influence survival at Bonneville Dam.

4.2 Powerhouse and Turbine Survival

Survival estimates through a powerhouse are not the same as individual turbine-specific survival estimates. Powerhouse survival reflects effects incurred by a population of fish naturally dispersed and passing through all operating units, not just a single test unit. Thus the estimate is more comprehensive.

Counihan et al. (2002b) reported survival estimates for powerhouse-passed fish in 2001. Using radio-tagged yearling Chinook salmon released at Hood River, Oregon, they estimated the overall combined survival of yearling Chinook salmon passing through any turbine unit at Bonneville Dam. Controls were released below the JBS outfall. They reported relative survival as 0.929 (S.E. = 0.02) for all turbine-passed fish. This value was nearly the same as the survival they calculated for non-turbine-passed fish (0.937; S. E. = 0.02), which included those collectively using the spillway and bypass systems.

In 2002, Counihan et al. (2003) reported similar types of survival estimates, but not identical to the overall powerhouse-passed category. They estimated survival through B1 and B2 powerhouses separately for radio-tagged yearling Chinook salmon. Total effects relative to control groups released below the JBS outfall were estimated as 0.902 for fish passing B1 and 0.993 at B2. The high survival through B2 and fish passing the entire dam (0.977) may seem unrealistically high to some parties. If dead treatment fish drifted to the recovery sites, this could explain the situation. But the investigators did not report this as being a problem in 2002.

In 2004 and 2005 there was no standard operation in place at Bonneville Dam. Instead, a variety of spill operations were tested to assess effects on route-specific survival, including through the powerhouses. Survival through various routes was affected by prevailing spill test conditions. Thus we do not report a season-wide estimate, since it presents limited insight and may be confusing.

In addition to powerhouse-wide estimates, turbine unit-specific survival estimates are commonly obtained at dams, including Bonneville. These studies usually involve releasing treatment fish through specific turbine units via a hose, paired with control group releases somewhere in the tailrace. Holmes (1952) first estimated survival at Bonneville Dam using this technique. Studies were conducted in June and early July using fin-clipped hatchery fall Chinook salmon. Based on adult recoveries, he estimated that the average survival through a turbine was 88.5% (11.5% loss as he reported). This estimate reflects the total effects incurred from the turbine intake to the control site(s) located several hundred meters downstream from either the spillway or powerhouse. However, hose releases may have been compromised since the head on the hose differed for treatment and control releases. Control fish releases had a higher head, which could have inflicted higher mortality based on independent tests, resulting in an overestimate of treatment survival, since the controls may have incurred an additional release-related effect. This point was not prominently noted in the reported results. Also, precision associated with the estimates was relatively poor and therefore statistical tests could not demonstrate a significant difference from an accompanying spill bay survival estimate of 97%.

The next series of investigations that assessed the effects of turbine passage on smolt survival (as part of a much broader research effort) commenced in 1987 and continued in most years through 1992.

However, the scope of those studies was broad and involved a variety of treatments and reference (control) releases that varied through the years (Dawley et al. 1988 and 1989; Ledgerwood et al. 1990, 1991 and 1994). The NOAA Fisheries conducted these studies using hatchery fall Chinook salmon bearing both freeze-brands and coded wire tags (CWT). Short-term survival was estimated using branded fish recovered with seines near Jones Beach. Long-term survival was to be based on recoveries of CWT at hatcheries and within the fishery. But adult return rates were so low that meaningful comparisons among treatment and reference groups were impractical (Gilbreath et al. 1993).

Typically, survival estimates were not expressed as absolute values referenced to any specific control release. Rather, relative differences in survival among the particular suite of releases became the index of performance. This method was adopted, since over the years it became apparent that the location of the control release affected the magnitude of treatment effects being characterized. Treatments included turbine, bypass, and spillway passage effects, which were determined by releasing marked fish directly into those routes using hoses. Control or reference groups were released at a variety of locations over the years, including the Washington shore near Hamilton Island, offshore in the same area, and in the vicinity of the B2 bypass outfall. This shifting of controls was driven by the previous year's results, which were often surprising and thus posed new management concerns and ultimately new objectives for the ensuing study.

Dawley et al. (1993b) and Ferguson (1993) attempted to draw all of these assorted estimates together by adopting "differences in relative survival among passage routes" as a common currency to view information across years. Dawley's findings on relative survival for B2 in 1987, 1988, 1989, and 1990 and for B1 in 1992 are shown in Table 4.2 (Table 1 from Dawley et al. 1993b).

Important findings from Dawley et al. (1993b) and Ferguson (1993) include the following:

1. At the Bonneville Powerhouse 2 during that era, turbine-passed fall Chinook salmon survived at higher rates than fish using the bypass system.

2. Fish passing through turbines near the ceiling survived at lower rates than deeper fish, but not significantly so.

3. These studies were conducted during the summer, when smolt mortality associated with predatory fish was high. This mortality factor was considered the most likely agent causing the low bypass survival. Predatory fish appeared to be focusing on the concentrated smolt source at the bypass outfall.

4. Survival through the B2 bypass was lower than that observed for any other passage route including the spillway.

Table 4.2. Differences in Relative Survival between Fish Passing through the Bypass Systems and other Passage Routes at Bonneville Dam based upon Juvenile Recovery Data from Estuarine Sampling (Reproduced from Dawley et al. 1993b).

Releases site / passage route	Percent difference of bypass recoveries from indicated treatment[a] 1987	1988	1989	1990	1992	Average
Second Powerhouse Bypass						
Turbine	Released at the ceiling and mid-depth of the turbine intake. Passage through the turbine and through the Second Powerhouse tailrace.					
	-10.8*	-13.6*	-3.3	-2.5[b]	---	-7.6*
Tailrace	Released at the downstream side of turbine discharge boil. Passage through the turbine and through the Second Powerhouse tailrace.					
	---	-14.1*	-7.3	-3.6	---	-8.3*
Spillway	Released 0.5m above the spillway crest. Passage over the spillway, through stilling basin and spillway tailrace.					
	---	---	-16.6*	---	---	-17.4*
Downstream	Released downstream of dam and tailraces at a swift water site.					
	---	-23.1*	-11.6*	---	---	-17.4*
First Powerhouse Bypass						
Turbine	Released at mid-depth of the turbine intake. Passage through the turbine and through the First Powerhouse tailrace.					
	---	---	---	---	-11.8*	-11.8*
Downstream	Released downstream of dam and tailraces at a swift water site.					
	---	---	---	---	-28.3*	-28.3*

[a] Calculated using annual means for recovery percent of treatment groups where BY = bypass and TR = other treatment groups/passage routes. [(BY% - TR%) ÷ TR%] x 100
[b] Only the mid-depth release site was used to provide increased numbers of replicates.
* Statistically significant at P = 0.95.

This series of studies illustrates how difficult it can be to assign an absolute value to smolt survival associated with turbine passage or passage through any route at this dam site. Clearly, such estimates are sensitive to the location of control releases. This will complicate matters for managers or modelers who strive to accurately index turbine or powerhouse survival for applications in model analyses.

4.3 Minimum Gap Runner Turbine Survival

From November 1999 through January 2000, Normandeau et al. (2000) estimated direct survival through minimum gap runner (MGR) turbines using balloon-tagged Chinook salmon (mean = 166 mm). Comparisons with existing turbine units indicated that the MGR yielded equivalent, or perhaps slightly better, survival. Test fish were released at different locations into the turbines (blade tip, mid-blade, and hub) over a range of four power generation levels. Overall, survival was highest for fish released near the hub, then mid-blade, and lowest at the blade tip regardless of turbine type. No significant correlation was found between survival and turbine operating efficiency in either type turbine.

Table 4.3 shows the average survival across the three blade locations relative to controls released at the exit of the draft tube, which we calculated from data presented in the executive summary of Normandeau et al. (2000).

Table 4.3. Mean Percent Direct Survival in 1999 for Balloon-Tagged Chinook Salmon Passed through a MGR and a Standard Turbine, Calculated from Normandeau et al. (2000). Power level 1 was the lowest and level 4 was the highest level tested.

		Turbine Power Level			
Turbine Type	**Unit**	**1**	**2**	**3**	**4**
Standard-Existing	5	96.0	96.4	96.5	96.0
MGR	6	96.7	95.7	97.0	96.2

The direct survival values in Table 4.3 based on balloon tag data differ substantially from those reported by Counihan et al. (2003). According to Counihan, mean survival through the MGR turbine varied with the release location of the control group. It was either 101% (control below JBS) or 106% (control at turbine front-roll; Table 4.4). Even if capped at 100%, these estimates of total effects do not comport with direct effects reflected in the Normandeau 2000 study. The estimates appear to be biased high and are not representative of actual effects. Some problem with the survival experiment protocol assumptions likely occurred. On the one hand, the passive drift of dead treatment fish to the detection transects would explain the incongruous estimates (although that problem was not reported as being observed with independent releases of tagged, dead fish). Alternatively, control fish may have, for some unexplained or unrecognized reason, incurred greater mortality than turbine-passed fish. This would result in a higher relative survival for the MGR fish. Whatever the cause, the absolute values obviously overstate true survival.

In 2004, Counihan et al. (2006a) again reported survival through MGR units. Survival estimates relative to two control release locations produced unexpected results. The highest survival estimates were obtained using controls released below the JBS, whereas those released in the frontroll produced the lowest survival (Table 4.4). The opposite is expected to occur. When controls are released further downstream, additional tailrace effects should be reflected in the survival estimate.

Skalski et al. (2002) re-analyzed Bonneville Powerhouse 1 balloon-tag data originally reported by Normandeau et al. (2000). Their objective was to describe the relationship between survival and turbine operating (efficiency) levels. They compared survival through a turbine unit (unit 5) at three release locations (blade tip, mid-blade, and near the hub), and four discharge levels. Estimated survival ranged from a low of 90.9% to 100.9%. The highest survival was associated with hub releases, but no correlation with turbine discharge (or operating efficiency) was evident. Fish released near the blade tip exhibited the lowest survival, with no relationship to discharge (operating efficiency). These results indicate that survival for smolts passing through the powerhouse is sensitive to their spatial distribution within the turbine.

Table 4.4. Comparison of Turbine Passage Survival Estimates from Several Studies, Reflecting either Direct or Total Effects

Investigators	Treatment Zone	Mean Survival (S.E.)	Species	Comment
		Indirect Effects		
Counihan et al. (2002b)	Collectively all turbines	0.929 (0.02)	Y. Chinook	Non-turbine passed = 0.937 (S.E. = 0.02)
Holmes (1952)	Individual turbines	0.885	S. Chinook	
Counihan et al. (2003)	Powerhouse 1	0.902 (0.036)	Y. Chinook	
Counihan et al. (2003)	Powerhouse 2	0.993 (0.036)	Y. Chinook	
		Direct Effects		
Normandeau et al. (2000)	MGR (Unit 6)	0.957-0.970[a]		
Normandeau et al. (2000)	Standard turbines	0.960-0.965[a]		
Counihan et al. (2003)	MGR	1.01-1.06	Y. Chinook	
Counihan et al. (2006a)	MGR	0.956 – 0.996	Y. Chinook	Front roll controls yielded lowest value
Counihan et al. (2006a)	MGR	0.952 – 0.974	Steelhead	`` ``

[a] Range in survival across four turbine-operating power levels.

It is difficult to ascertain whether minimum gap runners provide any substantive improvement in survival, given the suite of estimates currently available. However, in general, the MGR units appear to cause effects similar to the standard units based on the direct comparison reported by Normandeau et al. (2000).

4.4 Spill Survival

Through 2002, survival for the entire spillway at Bonneville Dam has only been estimated in one investigation. Counihan et al. (2003) estimated that 97.7% (S.E. = 0.14) of the radio-tagged yearling Chinook salmon survived passing the spillway. This value may be biased high for reasons discussed previously.

Survival through individual spill bays has been estimated by several investigators over the decades. Holmes (1952) was the first to conduct such a study. Using the same hose release protocol described previously, he estimated the survival of fall Chinook salmon to average 97% (3% loss in his terms). The same cautionary point made for the turbine survival estimates applies here. This value may overestimate actual survival through the spillway, since the author identified differential hose effects between a number of treatment and control releases.

4.4.1 Spillway Deflectors

With the development of spillway flow deflectors for gas abatement in the early 1970s, there was a need to assess the effects of these devices on smolt survival. Freeze-branded hatchery fall Chinook salmon were released into spill gates at the dam in July and August 1974 and subsequently recovered with beach seines at Jones Beach (Johnsen and Dawley 1974). We used their recovery data and calculated survival at 95.8% for the standard spill bays and 86.8% for the deflector-equipped spill bays, relative to controls released 1.6 km below the dam. This was the first indication that the presence of deflectors may decrease survival through the spillway.

Spillway deflectors became the focus of attention during the 1990s as the use of spill as a passage strategy intensified. In 1995, Normandeau et al. (1996) used balloon-tagged hatchery fall Chinook salmon to assess the effects of spillway deflectors at Bonneville Dam. One treatment group was released through a standard spill bay (Spill bay 2) and another group was released through a spill bay fitted with a deflector (Spill bay 4). Control fish were released into the tailrace. Survival through each spill bay was equivalent and was estimated at 1.0. In contrast to the findings of Johnsen and Dawley (1974), no mortality could be attributed to the presence of deflectors, at least under the conditions prevailing in 1995. Furthermore, injury rates through both spill configurations were modest at 1.3%.

The USACE continued to investigate the performance of spillway deflectors across a broader range of operating conditions. At Bonneville Dam, one strategy that was explored was the lowering of deflectors to ensure adequate submergence during low tailwater conditions. An assessment of a modified spillway deflector yielded confusing results in 2002. The intended treatments were one spill bay with a standard deflector (Bay 14) and another with the deflector lowered by seven feet (Bay 16). However, the amount of water discharged through each spill bay was different over the course of the investigation. Spill bay 16 consistently passed higher volumes of water, often ranging from 1,000 to 2,000 cfs more than Spill bay 14. Furthermore, two different spill regimes were examined (75 kcfs and a gas cap) during both the spring and summer tests. Results from Normandeau et al. (2003) were summarized as reported here (Table 4.5).

Significant differences in spill bay survival were not discernable at the precision levels attained. That may be moot since effects from deflector position may have been masked by the different flow volumes discharged through each spill bay. Apart from the main study objective of testing deflector types, a comparison of survival at the two spill regimes (high and low tailwater) indicated that during the summer, when the tailwater was low and temperatures were warm, estimated survival at the gas cap was near 100% and appeared considerably higher than the 88.6% survival observed at the 75 kcfs spill level. No clear, solid explanation was offered other than the implication that some gross spill volume effect may have occurred that was specific to the location of those particular spill bays.

In 2004, this matter was further examined using radio-tagged smolts (Counihan et al. 2006a). Three species, two spill conditions, and two deflector elevations were investigated. Results were mixed (Table 4.6). At the existing deflector elevation, survival was poor for all species at the nominal 75 kcfs spill level. Even the 7 ft deflector yielded suboptimal survival at 75 kcfs. Thus, the 75 kcfs condition does not appear to be the preferred operation in any season. With respect to spill level, the nominal gas cap yielded the highest estimates during the spring. But in the summer, the 75 kcfs spill condition produced higher survival. We use the term “nominal” here because the actual spill levels prevailing during the study were subsequently found to be in error and were recalculated by the USACE. Counihan et al. (2006a) reports that the spill discharge was generally 20 kcfs less than what had been reported

Table 4.5. Survival Estimates for Balloon-Tagged Chinook Salmon at Two Deflector Elevations and Spill Levels (Data from Normandeau et al. 2003)

Tailwater Condition	Spill bay 14 Existing Deflector Lower Discharge		Spill bay 16 7' Lowered Deflector Higher Discharge	
	75 kcfs	**Gas Cap**	**75 kcfs**	**Gas Cap**
High Tailwater (Spring – Cool)	97.9	98.6	95.9	99.0
Low Tailwater (Summer – Warm)	90.5	1.0	88.6	1.0

However, there are further considerations that complicate our ability to draw clear conclusions regarding the overall benefits of spill as a passage option. At face value, these spillbay survival estimates do not appear to comport with overall dam survival estimates reported by Counihan et al. (2006a) for 2004 (Table 4.1). Dam survival was high for both yearling Chinook salmon (95.1%) and steelhead (99.1%), higher than these estimates of spill survival would be expected to provide. However, one needs to consider survival and fish proportions passing through all routes to resolve this seeming incongruity. One explanation is that survival through other heavily used routes is appreciably higher than occurs at the spillway. That issue is explored in a subsequent section of this report.

Table 4.6. Survival Estimates (%) through Spillbays at Different Spill Regimes (Data from Counihan et al. 2006a). The 75 kcfs condition was actually about 20 kcfs lower than originally reported.

Species / Age	Existing Deflector elevation		7' - Lowered Deflector	
	75 kcfs	**Gas Cap**	**75 kcfs**	**Gas Cap**
Y. Chinook	77.3	94.6	93.7	94.3
Steelhead	85.0	101.2	92.7	97.9
S. Chinook	80.3	74.1	92.0	89.9

4.4.2 Bypass System Survival

4.4.2.1 Powerhouse 2; Original Bypass System

The first indication that the original Powerhouse 2 bypass system may be a source of pronounced smolt mortality came in 1987. Dawley et al. (1988) conducted the first of a series of annual investigations at the dam. Over the years 1987-1990 and 1992, it became evident that fall Chinook salmon survival was worse for fish passing through the bypass than for any other route including the turbines (Table 4.2). Years of study suggested that most of the bypass mortality was associated with fish predation concentrated near the outfall. These findings led to the construction of a new bypass conduit and outfall at B2.

In 1991 and 1992, NOAA investigators focused on experimentally isolating direct effects associated with the bypass system from indirect predator-related effects near the bypass outfall. To estimate direct effects, they attached a trap net to the outfall. Treatment fish were released at the upper end of the bypass system and matched with controls released directly in the net. Dawley et al. (1998) generally concluded that mortality and injury were minimal while fish passed through the bypass structure. This observation reinforced previous presumptions that the primary agent of bypass mortality was predator feeding in the vicinity of the outfall. However, Dawley et al. noted that short-term stress and fatigue associated with passage through the bypass may have increased smolt vulnerability to predation and indirectly contributed to total bypass-related mortality.

4.4.2.2 Powerhouse 2; New JBS

In 2000, Counihan et al. (2002a) estimated survival of radio-tagged yearling Chinook salmon passing through the new juvenile bypass system (JBS) at Bonneville Second Powerhouse. Treatment fish released into the upper end of the JBS were paired with controls released below the outfall. Survival was estimated as 0.98 (S.E. = 0.025), reflecting total survival through that zone.

In 2001, the same investigators repeated the evaluation of the JBS, using the same approach as in 2000 (Counihan et al. 2002b). They estimated survival as 0.962 (S.E. = 0.023) for yearling Chinook salmon and 0.90 (S.E. = 0.053) for subyearling Chinook salmon. In both years, survival through the JBS was high for yearling Chinook salmon.

4.4.2.3 Powerhouse 1; DSM

Dawley et al. (1993a) measured descaling and survival based upon trap-net catches of tagged juvenile salmonids in 1993, and found higher mortality for fish traveling greatest distances. For yearling Chinook salmon, mortality was about 0.9% for fish released at the down-well, 7.7% for fish released half-way down the channel, and 1.2% for fish released at the south end. Mortality for subyearlings (2.2%) did not differ from that of control fish released downstream. In 2002, Counihan et al. (2003) evaluated smolt survival through the downstream migrant bypass system (DSM) at the Bonneville First Powerhouse. Survival through the DSM at B1 was estimated by releasing radio-tagged fish into the bypass (treatment) and pairing those with releases below the JBS outfall at the powerhouse (control). Survival was low at 0.91, with a 95% CI of 0.081.

4.4.3 Outfall Survival

In planning the Bonneville Powerhouse 2 corner collector outfall, it was necessary to determine if there were deleterious effects associated with the impact between the outfall discharge jet and the receiving water in the tailrace. Direct survival was estimated for two outfall discharges (1,000 and 2,500 cfs) and two tailwater elevations (19.7 and 10.3 feet). Entry velocities ranged from 31 to 48 fps.

Effects of any treatment were negligible. At 48-h, survival was 99.6% to 100.0% across all four tailwater and discharge combinations. Injury rates were low at 0.7% for all treatment fish released during the study. The authors concluded that at the Bonneville Powerhouse 2 outfall when the impact velocity was less than or equal to 48 fps, mortality was negligible.

4.4.4 Route-Specific Survival - Recent Evaluations

The advent of new survival models has afforded the ability to estimate smolt survival through all routes at Bonneville Dam simultaneously. This permits direct comparisons among routes under common operating conditions. This approach was used in 2004 and 2005 (Counihan et al. 2006a; Counihan et al. 2006b). Using this method it is easier to determine which routes are actually the safest and thus the preferred routes. In those years survival estimates were calculated for a variety of spill operations. Survival estimates varied broadly, depending on species, passage route, and spill condition. Spill conditions examined included 75kcfs+gas cap night, 75 kcfs-day, and gas cap-night (in 2004 a 50 kcfs condition was also evaluated during the summer). With respect to the five primary passage routes, the main points we observed were

- Survival was always highest through the B2 corner collector - all species.
- The JBS at B2 typically ranked second or tied for first - all species.
- Ranking among the other three routes varied substantially, with no consistent pattern evident.

These rankings were determined by inspecting summary tables and figures appearing in the reports (Counihan et al. 2006a, 2006b). Depending on the species and prevailing condition, spillway survival was often low, ranking 4th or 5th of the five routes available. This may suggest that spill is not particularly beneficial for enhancing passage survival for the population at large. However, spilling water also enhances egress conditions in the tailrace and likely contributes to the high survival realized at the corner collector. We did not encounter any assessments that focused on determining what volume discharged through particular spillbays is required to produce adequate egress conditions.

The investigators used route-specific survival estimates to calculate dam passage survival under the different spill conditions. We view this as a more instructive performance index, because it reflects not only survival through routes but the proportion of the tagged population passing each route, as well as any indirect benefits associated with tailrace egress conditions. A consistent pattern is evident; during the gas cap-night condition, survival is highest for all species in both years. The only qualification is that, in 2004, the survival of subyearling Chinook salmon was uniform across the spill conditions.

Table 4.7. Dam Survival Estimates (%) as Derived from Route-Specific Estimates at Bonneville Dam in 2004 and 2005. Data were taken from tables appearing in the executive summary from Counihan et al. (2006a, 2006b).

		Spill Condition		
Year	**Species**	**75kcfs-day**	**Gas cap-night**	**75kcfs+gascap**
2004	Y. Chinook	92.5	97.9	95.1
	Steelhead	98.2	100	99.1
	S. Chinook	88.2	88.8	89.1
2005	Y. Chinook	95.5	97.8	96.6
	Steelhead	95.7	97.0	96.3
	S. Chinook	91.6	98.5	93.8

4.5 Synthesis and Conclusions

Comparisons of survival estimates from assorted investigations can be confusing at times. Nearly every treatment estimate reported herein is probably best viewed as a relative estimate of survival. The control release sites establish the reference point, and the recovery of control fish constitutes the tag recovery proportions for the condition specific to that time and space.

Not all studies have released controls in the same locations. Even within a multi-year study conducted by the same investigation team, the location of control release sites can vary. Similarly, the location where and the means by which treatment groups are released has varied across studies. These attributes can, in turn, affect the survival estimates. Managers must select those estimates that best reflect the zone of interest and the set of conditions that are of primary concern and then focus on survival estimates that best bracket those parameters. We have attempted to provide that information in this report to guide those management decisions.

Survival through minimum gap runner turbines tested at Bonneville appears equivalent to that realized for smolts passing through standard units. Thus, the MGR provides no discernable improvement in turbine passage survival. Balloon tag survival estimates are clear on this point, although the potential for some delayed effects associated with injury could be manifested as increased survival well downstream from the dam. Radio tag-based survival estimates did not shed light on this potential effect. Survival through a standard unit was not available for direct comparison with the MGR estimate.

The absolute values of a number of survival estimates that were obtained using radio telemetry are suspicious, since they approach or exceed 100%. Indications are that they were likely biased high. This was because in several instances a key assumption was violated. Independent tests revealed that some known dead fish bearing active tags released in the tailrace were subsequently detected at downstream detection transects. This raises the possibility that some smolts killed during dam passage could have drifted to the detection sites and been logged as live fish. The extent to which this actually occurred cannot be accurately determined. Perhaps relocating the downstream detection sites could avert this problem in the future.

Despite the uncertainty regarding bias associated with the absolute values of some telemetry estimates, the technique can still be used to generate acceptable estimates of relative survival. Thus use of this tool for determining optimal passage routes or operations appears sound if based on relative estimates. Conversely, it may require caution on the part of managers to rely on these telemetry-based survival estimates as input for passage modeling at Bonneville, because they may be mischaracterizing the true magnitude of passage effects.

Other mark-recapture approaches may not experience the difficulties unique to telemetry, but they are not without limitations. The absolute values of survival estimates obtained using freeze brands varied widely depending on the location at which the controls were released. As a consequence, those investigators expressed results as relative differences in recovery proportions to avoid the complication (Dawley et al. 1993b).

Absolute values generated using balloon tags appear sound and are readily interpretable. But of course they only reflect direct effects. Managers that are intent on analyzing the full passage effects through the FCRPS desire estimates that reflect total passage effects. For such purposes, managers will be forced to select judiciously from the estimates reported to date and select those that best reflect the zones and class of effects they wish to incorporate in their analyses. We cannot identify a best universal set of estimates that are suitable for all applications.

Radio tags provide a sound means to evaluate the effects of recent operations, using dam survival estimates derived from route-specific estimates. Furthermore we see this as an instructive performance index. In 2004 and 2005, survival during the gas-cap-night condition consistently was highest for all tagged species, except for subyearling Chinook salmon survival, which was uniform across all spill conditions. If future conditions need to be evaluated, a fruitful analytical approach is at hand. Again, we suggest the reader consider these as relative survival estimates, not absolute survival probabilities.

In our opinion, the affects of deflector elevation on spillway survival is becoming clearer, as evidenced by recent estimates compiled in Table 4.6. Based on radio tag data, the lower deflector yielded higher (or equivalent) survival than the 14 ft deflector, regardless of the spill level, species, or season. The only exception may be for steelhead under gas cap spill levels. It appears that the lowered deflector is the preferred configuration, although another year of testing may be prdent.

The safest passage routes at Bonneville Dam are the B2 corner collector and the B2 JBS. Operations that maximize passage through these routes are advantageous to the population. This appears to hold for all species tested thus far. The ranking of survival among the three other routes reveals no clear and consistent pattern.

5.0 Optimizing Juvenile Fish Passage Strategies at Bonneville Dam

5.1 Historical Perspective

Stated goals for juvenile salmonid passage at Bonneville Dam have changed over the years. Before B2 was completed in late 1982, spill was not a requirement for passing juvenile salmonids at Bonneville Dam. Spill was adequate even in low-flow years as it occurred whenever river discharge exceeded the hydraulic capacity of B1 (136,000 cfs through all turbines). From 1983 through about 1992, restrictions on B2 turbine operations during fish-passage seasons usually resulted in spill, much as it did in earlier years. Turbines at B2 were only operated as needed to limit spill to 75,000 cfs during the day or for fishery research testing at single units. From 1992 through 1994, the Portland District adopted a goal of 70% FPE for yearlings and 50% FPE for subyearlings from the Northwest Power Planning Council's Fish and Wildlife Program. This goal was also stated in the 1994 Biological Opinion by the National Marine Fisheries Service. The 1995 Biological Opinion called for spill at all projects to achieve 80% project FPE, but recognized that a daytime spill cap of 75,000 cfs to reduce adult fallback and low FGE at in-turbine screens probably would prevent spill from achieving that goal at Bonneville Dam.

The Washington Department of Fish and Wildlife (WDFW), Oregon Department of Fish and Wildlife (ODFW), Idaho Department of Fish and Game (IDFG), and Columbia River Inter-Tribal Fish Commission (CRITFC) (1995) supported spill at Bonneville Dam because in their analysis the risk to juvenile salmonids passing a spillway was lower than for those passing through turbines as long as spill-generated total dissolved gas levels did not exceed 120% to 125% of supersaturation. As a result of this report, NOAA Fisheries recommended using spill at mainstem projects to reach a goal of 80% FPE in the 1995 Opinion and its supplements through 1998. The 2000 Biological Opinion called for action agencies to continue to provide spill for fish passage. References to FPE were noticeably absent from the 2004 Biological Opinion, mention of survival criteria was very common, and the assumption that spill provides the best survival was retained, as indicated by the following excerpt:

> In developing the reference operation, as further described in Appendix D, NOAA Fisheries adjusted the operational parameters for the FCRPS to maximize fish survival based on the best science available and guided by NOAA Fisheries' juvenile fish passage strategy, which was originally developed in the 2000 FCRPS Biological Opinion (Section 9.6.1.4.1) and has been subsequently updated for this Opinion (Section 5.2.1.1.1.2). For example, the preferred passage method for most juvenile salmonids in the strategy is spillway passage, since spilling water over the spillways up to the current state water quality gas standard level is the option that provides dam passage with the least mortality, and therefore the reference operation calls for the use of additional spill for fish passage.

5.2 The Safest Passage Routes

Now that we have more years of survival data for Bonneville Dam, it may be time to reassess the underlying assumption of relative risk by ranking of routes by season and survival based upon data from active tagging studies. Information provided in Chapter 4 indicates that the spillway is not the safest passage route at the Bonneville Project. According to Table 4.8, it ranked second behind the B2CC out of six possible passage routes for steelhead and fourth behind the B2CC, B2 JBS, and B1 turbines for yearling Chinook salmon. For summer, the spillway ranked fourth behind the B2CC, B1 sluiceway, and B2 JBS in 2004 when spillway survival was 74.4%-87.6% (Table 4.9). The spillway ranked fifth in 2005 when survival was 91.1% and this rate did not differ from that of B2 turbines (89.5%), which were ranked sixth. The B2 Corner Collector consistently provides the highest survival for all migration periods, species, and treatments. Ranking among other routes is more variable, and survival probabilities are so similar that real differences likely do not exist in most cases. Certainly the proportion of smolts using the various routes factors greatly into any assessment. We recommend that the managers embark on some simple passage modeling exercises to formulate effective and safe passage strategies at the Bonneville Project.

5.3 Considerations for Performance Goals

Currently, in the remand process for the Biological Opinion, dam survival performance standards are being proposed. One of those standards is the dam survival metric of 95% per dam, averaged across a series of dams in the system. Presumably, any mix of passage routes that yields the desired dam survival standard should be satisfactory. However, establishing an absolute standard presumes one can monitor and estimate survival at each dam in absolute, not relative, terms. This may be difficult to accomplish at Bonneville where survival through some routes is obviously inaccurate (>100%). Biased route survival estimates can bias the dam survival estimates to some degree, depending on the analytical model. This matter deserves consideration by those agencies charged with prescribing passage strategies and associated monitoring.

An alternative goal at Bonneville could be to formulate passage strategies that maximize survival for the species of interest. Simple modeling exercises using observed variability in passage proportions and relative survivals could be conducted to explore scenarios. Data presented herein provide grist to conduct such exploratory analyses. Side-by-side comparisons between steelhead and yearling Chinook salmon are warranted, since the ranking of survival among routes varies for those co-mingled migrants.

5.4 Possible Measures to Improve Survival

We offer measures for managers to consider for improve juvenile passage survival for each major route at Bonneville Dam.

5.4.1 Bonneville Powerhouse 1

There have been four main passage routes at B1: intake screen juvenile bypass system, turbines, and surface flow outlets (including the sluiceway), and the prototype surface collector. It is reasonable to assume that intake screen technology is likely not a viable solution at B1 in the near or long term, given the regional agreement to remove the devices in recent years. Turbine passage survival, although based on telemetry-based estimates, has been reasonable for spring migrating fish (Table 4.8) but very poor for summer migrating fall Chinook salmon (Table 4.9). This leaves surface flow outlets as the primary means for a non-turbine passage route at B1. The existing sluiceway is known to pass fish and, while improvements are being made, more could be done. The PSC had fish collection efficiencies greater than 80% extrapolated to the entire powerhouse (Sweeney et al. 2007). Surface flow outlet approaches or enhancements are worth considering.

The B1 sluiceway will be refurbished by 2008 with auto-adjusting chain gates and a new collection channel. Managers should also consider improvements to provide safer passage conditions for fish at the conveyance structure at the terminus of the channel and the outfall. The drop at the end of the channel could be replaced with an ogee. The conveyance channel could lead to a new, custom-designed high-flow outfall. BioAnalysts et al. (2000), in a preliminary site selection study for a high-flow SFO outfall for B1, identified several possible locations that might be applicable to a new B1 sluiceway outfall.

A partial powerhouse retrofit SFO with vertical slot entrances was identified by Harza et al. (2001) during the post-PSC period. This concept might be reconsidered given that improvements to the sluiceway might include a new conveyance structure and outfall. The B1 powerhouse could have a vertical slot retrofit SFO in front of Units 1-6 and a sluiceway SFO at Units 7-10. This would provide a combination SFO that may benefit more species and age classes than either SFO alone.

In the original SFO alternatives report for B1, Harza and ENSR (1996) identified numerous SFO concepts, including one called Alternative A. Alternative A was a full powerhouse retrofit SFO with ten vertical slot entrances, each corresponding to a turbine unit, and a high-flow conveyance channel and outfall. It was estimated that the Alternative A structure would costs tens of millions of dollars. However, if one considers operation of Bonneville Dam without spill, Alternative A might become cost-effective.

5.4.2 Spillway

Spill to pass juvenile salmonids at Bonneville is often, but not always, a viable strategy; it depends on the season. If spill survival is as high as that of the B2CC and other surface passage routes, which it is in spring, then spill should be used to the extent necessary to supplement safe passage by the best surface flow outlets (B2CC) and perhaps the B1 sluiceway, after improvement to the channel, control gates, and possibly the outfall in the future. The SFOs are five or six times more effective than the spillway for passing juveniles because they have very high efficiency at low percentage discharge (see Section 3.2). In summer, the spillway should be used only after passage has been maximized through all other routes that have better survival. Survival of fish passing the spillway has been observed to decline as summer progresses, but survival of fish passing the B2CC is consistently high according to a 2006 survival study (Ploskey et al. 2007). Clearly, seasonal trends in survival must be considered in any optimization strategy for the spillway at Bonneville Dam.

Strategies for maximizing spillway survival include the existing configuration, low elevation deflectors, and high elevation deflectors. Although not significant at a 5% level, trends in data from Counihan et al. (2006a) support an alternative hypothesis that survival is lower at bays with 14-ft elevation deflectors (Bays 4-15) than at end bays with 7-ft elevation deflectors (Bays 1-3 and 16-18). If these differences are real, then it might be worth considering lowering deflectors at Bays 4-15, or even replacing fixed deflectors with moveable ones that function optimally at all tailwater elevations. Results from Normandeau et al. (2003) and Counihan et al. (2006a) also suggest that low spill volume through individual bays and low tailwater pool elevations may reduce survival.

Surface spill SFOs, such as a removable spillway weir (RSW), are popular, but do they make sense for the Bonneville Dam spillway given the Project's configuration? There is only one reason, in our opinion, that might justify installing an RSW at the spillway -- an RSW would increase surface flow, which might thereby attract fish from adjacent, poorer-survival passage routes at the spillway. For example, RSWs in Bays 2 and 16 might attract fish that otherwise may pass at interior Bays 4 through 15. Those bays have standard (high-elevation) deflectors that potentially provide lower survival than end bays with low-elevation deflectors, as described above. The cost-effectiveness of installing two RSWs would have to be compared with other options for altering spill deflectors, as described in the previous paragraph. Given the islands separating the spillway from the powerhouses at BON, it is unrealistic to think that an RSW might increase spill-passage efficiency or effectiveness as it might at other dams where fish could be attracted from a powerhouse. An RSW has the potential to reduce forebay residence times for some species, but they are already short at the Bonneville spillway, averaging 0.21 hours for yearling

Chinook salmon, 0.34 hours for steelhead, and 0.77 hours for subyearling Chinook salmon. Multiple RSWs with associated training spill would likely be required, potentially reducing any cost benefits.

5.4.3 Bonneville Powerhouse 2

A forebay guidance structure might be useful to divert fish from the northern half of the forebay to the B2CC entrance. A guidance wall concept to divert fish to the spillway was the subject of a previous preliminary engineering design (CH2M Hill et al. 1998). The authors concluded that the B2 wall concept had sufficient merit to warrant continued investigation, but new models and acquisition of additional biological and physical information would be required. They recommended a process to acquire the necessary information.

Managers might consider a second corner collector for the northern corner of the B2 powerhouse forebay. Harza and ENSR (1996b) mentioned this idea over ten years ago. Flow might be dewatered and plumbed into the low-flow JBS conveyance pipe if there is available capacity.

A smooth face to the plane of the powerhouse at the pier noses and above the turbine intakes would reduce turbulence along the face of the dam and might improve entrance conditions at the B2CC. While said conditions are relatively good, incremental improvement may increase B2CC forebay collection efficiency, particularly for juvenile Chinook salmon, which lag far behind steelhead.

6.0 Literature Cited

Adams, N. S., R. E. Reagan, S. D. Evans, M. J. Farley, L. S. Wright, and D. W. Rondorf. 2006. *Movement, Distribution, and Passage Behavior of Radio-Tagged Juvenile Chinook Salmon and Steelhead at Bonneville Dam, 2005*. Draft Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Anglea, S.M., K.D. Ham, G.E. Johnson, M.A. Simmons, C.S. Simmons, E. Kudera, and J. Skalski. 2003. *Hydroacoustic Evaluation of the Removable Spillway Weir at Lower Granite Dam in 2002.* Final Report PNNL-3219, to the U.S. Army Corps of Engineers District, Portland, OR, by Pacific Northwest National Laboratory, Richland, WA.

BioAnalysts, ENSR, and INCA. 2000. *Bonneville First Powerhouse High Flow Outfall Site Selection Study*. Final submittal to the U.S. Army Corps of Engineers, Portland, Oregon.

Biosonics, Inc. 1998. *Hydroacoustic Evaluation and Studies at Bonneville Dam, Spring/Summer 1997.* Final report to the U.S. Army Corps of Engineers, Portland District, by Biosonics, Inc., Seattle, Washington.

Bisson, P. A., C. C. Coutant, D. Goodman, J. Lichatowich, W. Liss, L. McDonald, P. R. Mundy, B. Riddell, R. Whitney, and R. Williams. 1999. *Review of the U.S. Army Corps of Engineers' capital construction program. Part II. A. Development and testing of surface bypass*. Independent Scientific Advisory Board ISAB Report 99-4 to the Northwest Power Planning Council and NMFS. February 16, 1999, Portland, OR.

CH2M-Hill/Montgomery Watson, BioAnalysts, Inc., and Pacific Northwest National Laboratory. 1998. *Bonneville Dam Second Powerhouse Physical Guidance Device*. Letter report submitted to Portland District, U.S. Army Corps of Engineers.

Committee on Fishery Operations. 1979. *A Summary of the Special Operations and Activities of Committee on Fishery Operations during the 1978 Spring and Summer Migrations*. Columbia River Water Management Group.

Committee on Fishery Operations. 1980. *1979 Annual Report.* Columbia River Water Management Group. Available online: http://www.nwd-wc.usace.army.mil/crwmg/crwmg_reports.htm

Committee on Fishery Operations. 1981. *1980 Annual Report*. Columbia River Water Management Group. Available online: http://www.nwd-wc.usace.army.mil/crwmg/crwmg_reports.htm

Committee on Fishery Operations. 1982. *1981 Annual Report*. Columbia River Water Management Group. Available online: http://www.nwd-wc.usace.army.mil/crwmg/crwmg_reports.htm

Committee on Fishery Operations. 1983. *1982 Annual Report*. Columbia River Water Management Group. Available online: http://www.nwd-wc.usace.army.mil/crwmg/crwmg_reports.htm

Committee on Fishery Operations. 1985. *1983 Annual Report*. Columbia River Water Management Group. Available online: http://www.nwd-wc.usace.army.mil/crwmg/crwmg_reports.htm

Counihan, T. D., J. H. Petersen, N. S. Adams, R. S. Shively, and H. C. Hansel. 2002a. *Feasibility of Extracting Survival Information from Radio-Telemetry Studies at the John Day Dam, 1999.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Counihan, T. D., K. J. Felton, G. Holmberg, and J. H. Peterson. 2002b. *Survival Estimates of Migrant Juvenile Salmonids in the Columbia River through Bonneville Dam Using Radio-Telemetry.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Counihan, T. D., G. S. Holmberg, and J. H. Petersen. 2003. *Survival Estimates of Migrant Juvenile Salmonids through Bonneville Dam using Radio-Telemetry, 2002*. Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Counihan, T.D., J. Hardiman, C. Walker, A. Puls, and G. Holmberg. 2006a. *Survival Estimates of Migrant Juvenile Salmonids through Bonneville Dam Using Radio Telemetry, 2004*. Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Counihan, T.D., J. Hardiman, C. Walker, A. Puls, and G. Holmberg. 2006b. *Survival Estimates of Migrant Juvenile Salmonids through Bonneville Dam using Radio Telemetry, 2005*. Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Dauble, D., S. Anglea, and G. Johnson. 1999. *Surface Flow Bypass Development in the Columbia and Snake Rivers and Implications Related to Research at Lower Granite Dam*. Final report prepared by Pacific Northwest National Laboratory for the Walla Walla District, U.S. Army Corps of Engineers. July 21, 1999.

Dawley, E. M., L. G. Gilbreath, and R. D. Ledgerwood. 1988. *Evaluation of Juvenile Salmonid Survival through the Second Powerhouse Turbines and Downstream Migrant Bypass System at Bonneville Dam, 1987.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest and Alaska Fisheries Science Center, Seattle, Washington.

Dawley, E. M., L. G. Gilbreath, R. D. Ledgerwood, P. J. Bentley, B. P. Sanford, and H. H. Schiewe. 1989. *Survival of Subyearling Chinook Salmon which Have Passed through the Turbines, Bypass System, and Tailrace Basin of Bonneville Dam Second Powerhouse, 1988*. Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest and Alaska Fisheries Science Center, Seattle, Washington.

Dawley, E. M., R. D. Ledgerwood, L. G. Gilbreath , B. P. Sandford, P. J. Bentley, M. H. Schiewe , and S. J. Grabowski. 1992. *Passage and Survival of Juvenile Chinook Salmon Migrating from the Snake River Basin.* Proceedings of a technical workshop held February 26-28, 1992, University of Idaho. Moscow, Idaho.

Dawley, E. M., L. G. Gilbreath, R. D. Ledgerwood, P. J. Bentley, and S. J. Grabowski. 1993a. *Direct Measure of Stress, Descaling, Injury and Mortality for Juvenile Salmonids Passing through the Bypass System of the Bonneville Dam First Powerhouse*. Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

Dawley, E. M., R. D. Ledgerwood, L. G. Galbreath , P. J. Bently, and S. J. Grabowski. 1993b. *Do bypass systems protect salmonids at dams*? Pages 161-168 in Proceedings of the Symposium on Fish Passage Policy and Technology, 1-2 September 1993, Portland, OR. Am. Fish Soc., Bioengineering Section, Bethesda, MD.

Dawley, E. M., L .G. Gilbreath, R. D. Ledgerwood , P. J. Bentley, and B. P. Sandford. 1998. *Effects of Bypass System Passage at Bonneville Dam Second Powerhouse on Downstream Migrant Salmon and Steelhead; Direct Capture Assessment, 1990-1992*. Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

DeHart, D. A. 1987. "*Downstream Migrant Juvenile Salmonid Protection Systems for Low to Medium Head Hydroelectric Dams*." Doctoral dissertation submitted to the University of Washington, Seattle, Washington.

ENSR Corporation, Harza Northwest, Inc., Inca Engineers, Inc., and Cornforth Consultants, Inc. 1998. *Bonneville First Powerhouse Juvenile Fish Surface Bypass High Flow Dewatering Facility and Outfall Alternatives Study*. Final report submitted to Portland District, U.S. Army Corps of Engineers. October 1998.

ENSR Corporation, Harza Northwest, Inc., Inca Engineers, Inc., and Cornforth Consultants, Inc. 1999. *Bonneville First Powerhouse Juvenile Fish Surface Bypass High Flow Dewatering Facility and Outfall Alternatives Study*. Final report for the U.S. Army Engineer District, Portland, OR.

ENSR Corporation and Inca Engineers, Inc. 2000. *Bonneville Second Powerhouse Corner Collector Outfall, 1:30 Scale Physical Hydraulic Model*. 30% submittal model study report for the U.S. Army Engineer District, Portland, OR.

Evans, S. D., J. M. Plumb, A. C. Braatz, K. S. Gates, N. S. Adams, and D. W. Rondorf. 2001a. *Passage Behavior of Radio-Tagged Yearling Chinook Salmon and Steelhead at Bonneville Dam Associated with the Surface Bypass Program, 2000.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Evans, S. D., N. S. Adams, and D. W. Rondorf. 2001b. *Passage Behavior of Radio-Tagged Subyearling Chinook Salmon at Bonneville Dam Associated with the Surface Bypass Program, 2000.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Evans, S. D, C. D. Smith, N. S. Adams, and D. W. Rondorf. 2001c. *Passage Behavior of Radio-Tagged Yearling Chinook Salmon at Bonneville Dam, 2001.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Evans, S. D, C. D. Smith, N. S. Adams, and D. W. Rondorf. 2001d. *Passage Behavior of Radio-Tagged Subyearling Chinook Salmon at Bonneville Dam, 2001.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Evans, S. D., L. S. Wright, C. D. Smith, R. E. Wardell, N. S. Adams, and D. W. Rondorf. 2003a. *Passage Behavior of Radio-Tagged Yearling Chinook and Steelhead at Bonneville Dam, 2002.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Evans, S. D., L. S. Wright, R. E. Wardell, N. S. Adams, and D. W. Rondorf. 2003b. *Passage Behavior of Radio-Tagged Subyearling Chinook at Bonneville Dam, 2002.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Evans, S., L. Wright, C. Smith, R. Wardell, N. Adams, and D. Rondorf. 2006a. *Passage Behavior of Radio-Tagged Yearling Chinook Salmon and Steelhead at Bonneville Dam, 2002: Revised for Corrected Spill.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Evans, S., L. Wright, R. Wardell, N. Adams, and D. Rondorf. 2006b. *Passage Behavior of Radio-Tagged Subyearling Chinook Salmon at Bonneville Dam, 2002: Revised for Corrected Spill.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Evans, S., L. Wright, R. Reagan, N. Adams, and D. Rondorf. 2006c . *Passage Behavior of Radio-Tagged Subyearling Chinook Salmon at Bonneville Dam, 2004: Revised for Corrected Spill.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Faber, D.M., M.A. Weiland, R.A. Moursund, and T.J. Carlson. 2001. *Evaluation of the Fish Passage Effectiveness of the Bonneville I Prototype Surface Collector using Three-Dimensional Ultrasonic Fish Tracking,* PNNL-13526, Prepared for U.S. Army Corps of Engineer District, Portland, Oregon by Pacific Northwest National Laboratory, Richland, Washington.

Ferguson, J. 1993. "Relative Survival of Juvenile Chinook Salmon through Bonneville Dam on the Columbia River," pp 58-65. In *Proceedings of the Workshop on Fish Passage at Hydroelectric Developments*, March 26-28, 1991, St. John's, Newfoundland. Canadian Technical Report of Fisheries and Aquatic Sciences, No. 1905, Department of Fisheries and Oceans, St. John's Newfoundland.

Ferguson, J. W., G. M. Matthews, R. L. McComas, R. F. Absolon, D. A. Brege, M. H. Gessel, and L. G. Gilbreath. 2005. *Passage of Adult and Juvenile Salmon Through Federal Columbia River Power System Dams*. NOAA Technical Memorandum, Fish Ecology Division, Northwest Fisheries Science Center, Seattle, WA, USA.

Gessel, M. H., R. F. Krcma, W. D. Muir, C. S. McCutcheon, L. G. Gilbreath and B. H. Monk. 1985. *Evaluation of the Juvenile Collection and Bypass Systems at Bonneville Dam - 1984.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest and Alaska Fisheries Science Center, Seattle, Washington.

Gessel, M. H., L. G. Gilbreath, W. D. Muir, B. H. Monk and R. F. Krcma. 1987. *Evaluation of the Juvenile Salmonid Collection and Bypass Systems at Bonneville Dam - 1986.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest and Alaska Fisheries Science Center, Seattle, Washington.

Gessel, M. H., B. H. Monk and J. G. Williams. 1988. *Evaluation of the Juvenile Fish Collection and Bypass Systems at Bonneville Dam -1987.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest and Alaska Fisheries Science Center, Seattle, Washington.

Gessel, M. H., B. H. Monk, D. A. Brege and J. G. Williams. 1989. *Fish Guidance Efficiency Studies at Bonneville Dam First and Second Powerhouses - 1988.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest and Alaska Fisheries Science Center, Seattle, Washington.

Gessel, M. H., D. A. Brege, B. H. Monk and J. G. Williams. 1990. *Continued Studies to Evaluate the Juvenile Bypass Systems at Bonneville Dam - 1989.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

Gessel, M. H., J. G. Williams, D. A. Brege, R. F. Krcma and D. R. Chambers. 1991. *Juvenile Salmonid Guidance at the Bonneville Dam Second Powerhouse, Columbia River, 1983-1989*. North American Journal of Fisheries Management 11:400-412.

Giorgi, A. E. and J. R. Stevenson. 1995. *A Review of Biological Investigations Describing Smolt Passage Behavior at Portland District Corps of Engineer Projects: Implications in Surface Collection Systems.* Prepared by Don Chapman Consultants, Inc. for the U.S. Army Engineer, Portland District, Portland, Oregon.

Gilbreath, L. G., E. M. Dawley, R. D. Ledgerwood, P. J. Bently, and S. J. Grabowski. 1993. *Relative Survival of Subyearling Chinook Salmon that have Passed Bonneville Dam Via the Spillway or Second Powerhouse Turbines or Bypass System: Adult Recoveries through 1991.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

Hansel, H. C., R. S. Shively, J. E. Hensleigh, B. D. Liedtke, R. E. Wardell, R. H. Wertheimer, and T. P. Poe. 1999. *Movement, Distribution, and Behavior of Radio-Tagged Juvenile Chinook Salmon and Steelhead in the Forebay of Bonneville Dam, 1998*. Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Harza Northwest, Inc. and ENSR Corporation. 1996a. *Surface Bypass Alternative Study at Bonneville First Powerhouse*. Volume 1. Final report submitted to Portland District, U.S. Army Corps of Engineers.

Harza Northwest, Inc. and ENSR Corporation. 1996b. *Surface Bypass Alternative Study at Bonneville Second Powerhouse.* Volume 2. Final report submitted to Portland District, U.S. Army Corps of Engineers.

Hensleigh, J. E., R. S. Shively, H. C. Hansel, B. D. Liedtke, K. M. Lisa, P. J. MacDonald, and T. P. Poe. 1998. *Movement, Distribution, and Behavior of Radio-Tagged Yearling Chinook Salmon and Juvenile Steelhead in the Forebay of Bonneville Dam, 1998.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Hensleigh, J. E., R. S. Shively, H. C. Hansel, J. M. Hardiman, G. S. Holmberg, B. D. Liedtke, T. L. Martinelli, R. E. Wardell, R. H. Wertheimer, and T. P. Poe. 1999. *Movement, Distribution, and Behavior of Radio-Tagged Juvenile Chinook Salmon and Steelhead in John Day, The Dalles, and Bonneville Dam Forebays, 1997.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Holmberg, G. S., R. S. Shively, H. C. Hansel, T. L. Martinelli, M. B. Sheer, J. M. Hardiman, B. D. Liedtke, L. S. Blythe, and T. P. Poe. 1996. *Movement, Distribution, and Behavior of Radio-Tagged Juvenile Chinook Salmon in John Day, The Dalles, and Bonneville Dam Forebays, 1996.* Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Holmes, H. B. 1952. *Loss of Fingerlings in Passing Bonneville Dam as Determined by Marking Experiments.* unpublished manuscript, U.S. Fish and Wildlife Service, Portland, Oregon.

INCA Engineers, Inc., FishPro, Inc., Northwest Hydraulic Consultants, Inc., R.W. Beck, AGRA Earth and Environmental, Inc., BioAnalysts, Inc., and Battelle Pacific Northwest Laboratories. 1997. *Bonneville Second Powerhouse Prototype Corner Collector*. Letter report submitted to Portland District, U.S. Army Corps of Engineers. November 21, 1997.

INCA Engineers, Inc., BioAnalysts, Inc., Chinook Engineering, ENSR, and R2 Resource Consultants. 1999. *Bonneville 2nd Powerhouse Fish Guidance Efficiency Improvement Study.* Report prepared for the U.S. Army Corps of Engineers, Portland District. Portland, Oregon.

INCA Engineers, ENSR, and BioAnalysts, Inc. 2001. Bonneville Second Powerhouse Corner Collector Site Selection Study. Technical Report under Contract No. DACW57-D-0003, Task Order No. 0013.

Johnsen, R. C., and E. M. Dawley. 1974. *The Effect of Spillway Flow Deflectors At Bonneville Dam on Total Gas Supersaturation and Survival of Juvenile Salmon*. Report to U.S. Army Corps of Engineers, Contract DACW-57-74-F-0122, 19 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Johnson, G. E., A. E. Giorgi, and M. W. Erho. 1997. *Critical Assessment of Surface Flow Bypass Development in the Lower Columbia and Snake Rivers,* completion report. Prepared for the U.S. Army Corps of Engineers, Walla Walla and Portland Districts, Portland, Oregon, by BioAnalysts, Inc., Vancouver, Washington.

Johnson, G., A. Giorgi, C. Sweeney, M. Rashid, and J. Plump. 1999. *High Flow Outfalls for Juvenile Fish Bypasses: Preliminary Guidelines and Plans for Research and Implementation.* Final Report submitted to U.S. Army Corps of Engineers by INCA Engineers, Portland District, Bellevue, Washington.

Johnson, G. E. and A. E. Giorgi. 1999. *Development of Surface Flow Bypasses at Bonneville Dam: A Synthesis of Data From 1995 to 1998 and a Draft M&E Plan for 2000.* Annual Report to U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by BioAnalysts, Inc., Vancouver, Washington.

Johnson, G. E., B. D. Ebberts, D. D. Dauble, A. E. Giorgi, P. G. Heisey, R. P. Mueller, and D. A. Neitzel. 2003. Effects of Jet Entry at High-Flow Outfalls on Juvenile Pacific Salmon. N. Am. J. of Fish. Manage. 23: 441-449.

Johnson, G. E. and T. J. Carlson. 2001. *Monitoring and Evaluation of the Prototype Surface Collector at Bonneville First Powerhouse: Synthesis of Results.* PNNL-13516, Prepared for the U.S. Army Corps of Engineers by Pacific Northwest National Laboratory, Richland, Washington.

Johnson, G. E. and D. D. Dauble. 2006. *Surface Flow Outlets to Protect Juvenile Salmonids Passing through Hydropower Dams*. Reviews in Fisheries Science 14: 213-244.

Johnson, R. L., R. A. Moursund, and M. A. Simmons. 1999. *Fish behavior in front of the prototype surface collector at Bonneville Dam in 1998.* Final report by the Pacific Northwest National Laboratory, Richland, WA for the Portland District, U.S. Army Corps of Engineers. February 22, 1999.

Johnson, R. L., M. A. Simmons, C. S. Simmons, K. D. Hand, and J. Thomas. 2000. *Hydroacoustic Evaluation of Fish Behavior in Front of the Prototype Surface Collector at Bonneville Dam, 1999.* Final report by the Pacific Northwest National Laboratory, Richland, WA, for the Portland District, U.S. Army Corps of Engineers.

Johnson, R. L., M. A. Simmons, C. S. Simmons, C. A. McKinstry, S. L. Thornsten, K. D. Hand, M. A. Chamness. 2001. *Hydroacoustic Evaluation of Fish Behavior at Bonneville Dam First Powerhouse: 2000 Prototype Surface Flow Bypass.* Final report by the Pacific Northwest National Laboratory, Richland, WA for the Portland District, U.S. Army Corps of Engineers.

Krcma, R. F., D. DeHart, M. Gessel, C. Long and C. W. Sims. 1982. *Evaluation of Submersible Traveling Screens, Passage of Juvenile Salmonids through the Ice-Trash Sluiceway, and Cycling of Gatewell-Orifice Operations at the Bonneville First Powerhouse, 1981.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest and Alaska Fisheries Science Center, Seattle, Washington.

Krcma, R. F., M. H. Gessel, W. D. Muir, C. S. McCutcheon, L. G. Gilbreath, and B. H. Monk. 1984. *Evaluation of the Juvenile Collection and Bypass System at Bonneville Dam - 1983.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest and Alaska Fisheries Science Center, Seattle, Washington.

Ledgerwood, R. D., E. M. Dawley, L. G. Gilbreath, P. J. Bently, B. P. Sanford, and M. H. Schiewe. 1990. *Relative Survival of Subyearling Chinook Salmon which have Passed Bonneville Dam via the Spillway or the Second Powerhouse Turbines or Bypass System in 1989, with Comparisons to 1987 and 1988.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

Ledgerwood, R. D., E. M. Dawley, L. G. Gilbreath, P. T. Bently, B. P. Sanford, and M. H. Schiewe. 1991. *Relative Survival of Subyearling Chinook Salmon that have Passed through the Turbines and Bypass System of Bonneville Dam Second Powerhouse, 1990.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

Ledgerwood, R. D., E. M. Dawley, L. G. Gilbreath, L. T. Parker, B. P. Sanford, and S. J. Grabowski. 1994. *Relative Survival of Subyearling Chinook Salmon after Passage through the Bypass System at the First Powerhouse or a Turbine at the First or Second Powerhouse and the Tailrace Basins at Bonneville Dam, 1992.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

Lee, R. and D. Schwartz. 2003. *Fish Guidance Efficiency Improvements 1995-2002 Prototype Design and Evaluations: Bonneville First Powerhouse.* U.S. Army Corps of Engineers - Portland District, Portland, Oregon.

Magne, R. A. 1987a. *Bonneville II Hydroacoustic Monitoring Memorandum for the Record, #1, 27 May 1987.* Report of the U.S. Army Corps of Engineers Fisheries Field Unit, Bonneville Lock and Dam, for the U.S. Army Corp of Engineers, Portland District, Portland, Oregon.

Magne, R. A. 1987b. *Hydroacoustic Monitoring at the Bonneville Dam Project in 1988 (a proposal plus 1987 data).* Report of the U.S. Army Corps of Engineers Fisheries Field Unit, Bonneville Lock and Dam, for the U.S. Army Corp of Engineers, Portland District, Portland, Oregon.

Magne, R. A. 1987c. *Hydroacoustic Monitoring of Downstream Migrant Juvenile Salmonids at Bonneville Dam, 1987.* U.S. Army Corps of Engineers, Portland District, Portland, Oregon. Report of the US Army Corps of Engineers Fisheries Field Unit, Bonneville Lock and Dam, for the U.S. Army Corp of Engineers, Portland District, Portland, Oregon.

Magne, R. A., D. J. Rawding and W. T. Nagy. 1986. *Hydroacoustic Monitoring at the Bonneville Dam Second Powerhouse during 1986 Fish Guidance Efficiency Tests.* Report of the U.S. Army Corps of Engineers Fisheries Field Unit, Bonneville Lock and Dam, for the U.S. Army Corp of Engineers, Portland District, Portland, Oregon.

Magne, R. A., R. Stansell, and W. T. Nagy. 1989. *A Summary of Hydroacoustic Monitoring at the Bonneville Dam Second Powerhouse in 1988.* Report of the US Army Corps of Engineers Fisheries Field Unit, Bonneville Lock and Dam, for the U.S. Army Corp of Engineers, Portland District, Portland, Oregon.

Michimoto, R. T. and L. Korn. 1969. *A Study to Determine the Value of Using the Ice-Trash Sluiceway for Passing Downstream-Migrant Salmonids at Bonneville Dam.* Prepared for the U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon, by the Fish Commission of Oregon, Research Division.

Michimoto, R. T. 1971. *Bonneville and The Dalles Dams Ice-Trash Sluiceway Studies, 1971*. Report #20, Prepared for the U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon, by the Fish Commission of Oregon, Research Division.

Monk, B. H., B. P. Sandford, and D. B. Dey. 1994. *Evaluation of Fish Guidance Efficiency of Submersible Traveling Screens and other Modifications at Bonneville Dam, Second Powerhouse 1993.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

Monk, B. H., M. H. Gessel and J. W. Ferguson. 1999a. *An Evaluation of the Biological Database for Improving Fish Guidance Efficiency at Bonneville Dam Second Powerhouse.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

Monk, B. H., B. P. Sandford, and D.B. Dey. 1999b. *Evaluation of Extended-Length Submersible Bar Screens at Bonneville Dam First Powerhouse, 1998.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

Monk, B. H. and B. P. Sandford. 2001. *Evaluation of Extended-Length Submersible Bar Screens at Bonneville Dam First Powerhouse, 2000.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

Monk, B. H., R. F. Absolon, B. P. Sandford and J. W. Ferguson. 2002. *Evaluation of Intake Modification at Bonneville Dam Second Powerhouse, 2001.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

Monk, B.H., B.P. Sandford, D.A. Brege, and J.W. Ferguson. 2004. *Evaluation of Turbine Intake Modifications at the Bonneville Dam Second Powerhouse, 2002.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest Fisheries Science Center, Seattle, Washington.

Moursund, R.A. K.D. Ham, P.S. Titzler. 2003. *Hydroacoustic Evaluation of Downstream Fish Passage at John Day Dam in 2002*. Final Report PNWD-3236, Pacific Northwest National Laboratory, Richland, WA, for the U.S. Army Corps of Engineers District, Portland, OR.

Muir, W. D., A. E. Giorgi, W. S. Zaugg and B. R. Beckman. 1989. *An Assessment of the Relationship Between Smolt Development and Fish Guidance Efficiency at Bonneville Dam.* Annual Report of Research for the U.S. Army Corps of Engineer District, Portland, Oregon by the National Oceanic and Atmospheric Administration, Northwest and Alaska Fisheries Science Center, Seattle, Washington.

Nagy, W. T. and R. A. Magne. 1986. *Hydroacoustic Study of Juvenile Fish Passage at the Bonneville Dam Second Powerhouse in 1985.* Report of the US Army Corps of Engineers Fisheries Field Unit, Bonneville Lock and Dam, for the U.S. Army Corp of Engineers, Portland District, Portland, Oregon.

National Marine Fisheries Service (NOAA Fisheries). 1995. *Biological Opinion on 1994-1998 Operation of the Federal Columbia River Power System and Juvenile Transportation Program.* National Marine Fisheries Service, Seattle, Washington.

National Marine Fisheries Service (NOAA Fisheries). 1998. *Biological Opinion on Operation of the Federal Columbia River Power System and Juvenile Transportation Program*. May 14, 1998.

National Marine Fisheries Service (NOAA Fisheries). 2000. *Biological Opinion: Reinitiation of Consultation on Operation of the Federal Columbia River Power System, Including the Juvenile Fish Transportation Program, and 19 Bureau of Reclamation Projects in the Columbia Basin.* National Marine Fisheries Service, Northwest Region, Seattle, Washington.

National Marine Fisheries Service (NOAA Fisheries). 2004. *Biological Opinion on Operation of the Federal Columbia River Power System and Juvenile Transportation Program*. December 2004.

Normandeau Associates Inc., J. R. Skalski, and Mid Columbia Consulting Inc. 1996. *Potential Effects of Spillway Flow Deflectors on Fish Condition and Survival at the Bonneville Dam, Columbia River,* Prepared for the U.S. Army Corps of Engineers – Portland District by Normandeau Associated Inc., Drumore, Pennsylvania.

Normandeau Associates Inc., J.R. Skalski, and Mid Columbia Consulting, Inc. 2000. *Direct Survival and Condition of Juvenile Chinook Salmon Passed through an Existing and New Minimum Gap Runner Turbines at Bonneville Dam First Powerhouse, Columbia River.* Prepared for US Army Corps of Engineers, Portland District, by Normandeau Associates, Inc. Drumore, Pennsylvania.

Normandeau Associates Inc., J. R. Skalski, and Mid-Columbia Consulting Inc. 2001. Passage survival investigation of juvenile chinook salmon through Bonneville Powerhouse II bypass sluice at two tailwater conditions Columbia River, Washington. Final report.

Normandeau Associates Inc., Mid Columbia Consulting Inc., and J. R. Skalski. 2003. J*uvenile Salmonid Survival and Condition in Passage through Modified Spillbays at Bonneville Dam, Columbia River.* Prepared for U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Normandeau Associated Inc., Drumore, Pennsylvania.

Ott Water Engineers, Inc. 1985. *Review and Study of the Bonneville Second Powerhouse Fish Guidance Efficiency Program.* Prepared for U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Ott Water Engineers, Inc.

Ploskey, G. R., L. R. Lawrence, P. N. Johnson, W. T. Nagy and M. G. Burczynski. 1998. *Hydroacoustic Evaluations of Juvenile Salmonid Passage at Bonneville Dam including Surface-Collection Simulations.* Technical Report EL-98-4 prepared for the U.S. Army Corps of Engineers - Portland District by the U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

Ploskey, G. R., W. T. Nagy, L. R. Lawrence, D. S. Patterson, C. R. Schilt, P. N. Johnson and J. R. Skalski. 2001a. *Hydroacoustic Evaluation of Juvenile Salmonid Passage through Experimental Routes at Bonneville Dam in 1998*. ERDC/EL TR-01-2, prepared for the U.S. Army Corps of Engineers - Portland District by the U.S. Army Corps of Engineers Engineer Research and Development Center, Environmental Laboratory, Vicksburg, Mississippi.

Ploskey, G. R., L. R. Lawrence, P. N. Johnson, C. R. Schilt, W. T. Nagy, D. S. Patterson, J. Skalski. 2001b. *Hydroacoustic Evaluation of the Bonneville Dam Prototype Surface Collector in 1999.* Final Report ERDC/EL TR-01-1, prepared for the U.S. Army Corps of Engineers - Portland District by the U.S. Army Corps of Engineers Engineer Research and Development Center, Environmental Laboratory, Vicksburg, Mississippi.

Ploskey, G.R., W.T. Nagy, L.R. Lawrence, M.E. Hanks, C.R. Schilt, P.N. Johnson, G.E. Johnson, D.S. Patterson, and J.R. Skalski. 2001c. *Hydroacoustic Evaluation of Juvenile Salmon Passage at The Dalles Dam: 1999*. ERDC/EL TR-01-11, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

Ploskey, G. R., C. R. Schilt, M. E. Hanks, J. R. Skalski, W. T. Nagy, P. N. Johnson, D. S. Patterson, J. Kim and L. R. Lawrence. 2002a. *Hydroacoustic Evaluation of Fish Passage through Bonneville Dam in 2000.* ERDC/EL TR-02-8, Prepared for the U.S. Army Corps of Engineers – Portland District, by the U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, Mississippi.

Ploskey, G. R., C. R. Schilt, M. E. Hanks, J. R. Skalski, W. T. Nagy, P. N. Johnson, D. S. Patterson, J. Kim and L. R. Lawrence. 2002b. *Hydroacoustic Evaluation of a Prototype Surface Collector and In-Turbine Screens at Bonneville Dam Powerhouse 1 in 2000.* ERDC/EL TR-02-15, Prepared for the U.S. Army Corps of Engineers – Portland District, by the U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, Mississippi.

Ploskey, G. R., C. R. Schilt, M. E. Hanks, P. N. Johnson, J. Kim, J. R. Skalski, D. S. Patterson, W. T. Nagy and L. R. Lawrence. 2002c. *Hydroacoustic Evaluation of Fish Passage Efficiency at Bonneville Dam in 2001.* PNNL-14047, Prepared for the U.S. Army Corps of Engineers, Portland District, by Pacific Northwest National Laboratory, Richland, Washington.

Ploskey, G. R., C. R. Schilt, J. Kim, C. W. Escher and J. R. Skalski. 2003. *Hydroacoustic Evaluation of Fish Passage through Bonneville Dam in 2002.* PNNL-14356, Prepared for the U.S. Army Corps of Engineers – Portland District, by Pacific Northwest National Laboratory, Richland, Washington.

Ploskey, G.R., M.A. Weiland, C. R. Schilt. 2004. *Evaluation of Fish Losses through Screen Gaps at Modified and Unmodified Intakes of Bonneville Dam Second Powerhouse in 2003,* PNNL-14539, Prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Ploskey G. R., M. A. Weiland, C. R. Schilt, P. N. Johnson, M. E. Hanks, D. S. Patterson, J. R. Skalski, and J. Hedgepeth. 2005. H*ydroacoustic Evaluation of Fish Passage through Bonneville Dam in 2004.* PNNL-15249, Pacific Northwest National Laboratory, Richland, WA, for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Ploskey, G. R., G. E. Johnson, M. A. Weiland, F. Khan, R. P. Mueller, J. A. Serkowski, C. L. Rakowski, J. B. Hedgepeth, J. R. Skalski, B. D. Ebberts, and B. A. Klatte. 2006a. "Acoustic camera evaluation of juvenile salmonid approach and fate at surface flow outlets of two hydropower dams." *HydroVision 2006* Conference held in Portland, Oregon. HCI Publications, Kansas City Missouri, USA.

Ploskey, G. R., J. Kim, M. A. Weiland, J. S. Hughes, and E. S. Fischer. 2006b. *Reanalysis of Hydroacoustic Fish-Passage Data from Bonneville Dam after Spill-Discharge Corrections.* Draft Report by the Pacific Northwest National Laboratory, Richland, WA, for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Ploskey, G. R., M. A. Weiland, S. A. Zimmerman, J. S. Hughes, K. Bouchard, E. S. Fischer, C. R. Schilt, M. E. Hanks, J. Kim, J. R. Skalski, J. Hedgepeth, and W. T. Nagy. 2006c. *Hydroacoustic Evaluation of Fish Passage through Bonneville Dam in 2005.* PNNL-15944, Pacific Northwest National Laboratory, Richland, WA, for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Plumb, J. M., M. S. Novick, B. D. Liedtke, and N. S. Adams. 2001. *Passage Behavior of Radio-Tagged Yearling Chinook Salmon and Steelhead at Bonneville Dam Associated with the Surface Bypass Program, 1999*. Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Portland District, Corps of Engineers. 2002. *Bonneville Decision Document: Juvenile Fish Passage Recommendation.* U.S. Army Corps of Engineers – Portland District, Portland, Oregon.

Rakowski C. L., J. A. Serkowski, M. C. Richmond, and K. P. Recknagle. 2001. *Development and Application of a 3D CFD Model for the Bonneville Project Powerhouse 1 and Powerhouse 2* . PNNL-13593, Pacific Northwest National Laboratory, Richland, WA.

Rakowski C.L., M.C. Richmond, J.A. Serkowski, and G.E. Johnson. 2005. *Forebay Computational Fluid Dynamics Modeling for The Dalles Dam to Support Behavior Guidance System Siting Studies.* PNNL-15689, Pacific Northwest National Laboratory, Richland, WA.

Reagan, R., S. Evans, L. Wright, M. Farley, N. Adams, and D. Rondorf. 2006. *Passage Behavior of Radio-Tagged Yearling Chinook Salmon and Steelhead at Bonneville Dam, 2004*: revised for corrected spill. Annual Report by the U.S. Geological Survey, Columbia River Research Laboratory, Cook, Washington for the U.S. Army Engineer District, Portland, Oregon.

Reservoir Control Center. 1985a. *Columbia River Fishery Operations 1984 Annual report*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1985b. *Juvenile Fish Passage Plan for 1985 for Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1986. *Operating Standards and Maintenance Plan for 1986*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1987. *Juvenile Fish Passage Plan for 1987 for Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1988. *Juvenile Fish Passage Plan for 1988 for Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1989. *Juvenile Fish Passage Plan for 1989 for Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1990. *Fish Passage Plan for 1990 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1991. *Fish Passage Plan for 1991 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1992. *Fish Passage Plan for 1992 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1993. *Fish Passage Plan for 1993 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1994. *Fish Passage Plan for 1994 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1995. *Fish Passage Plan for 1995 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1996. *Fish Passage Plan for 1996 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1997. *Fish Passage Plan for 1997 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1998. *Fish Passage Plan for 1998 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 1999. *Fish Passage Plan for 1999 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 2000. *Fish Passage Plan for 2000 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 2001. *Fish Passage Plan for 2001 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 2002. *Fish Passage Plan for 2002 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 2003. *Fish Passage Plan for 2003 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 2004. *Fish Passage Plan for 2004 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Reservoir Control Center. 2005. *Fish Passage Plan for 2005 Corps of Engineers Projects*. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Schneider, M. L., J. Carroll, C. C. Schneider, and K. Barko. 2003. *Total Dissolved Gas Exchange at Bonneville Dam, 2002 Spill Season*. Technical Report by the U.S. Army Engineer Research and Development Center for the U.S. Army Engineer District, Portland, USA.

Skalski, J. R., D. Mathur, and P. G. Heisey 2002. "Effects of Turbine Operating Efficiency on Smolt Passage Survival." *North American Journal of Fisheries Management* 22:1193–1200.

Stansell, R. J., R. A. Magne, W. T. Nagy and L. M. Beck. 1990. *Hydroacoustic Monitoring of Downstream Migrant Juvenile Salmonids at Bonneville Dam, 1989*. Report of the US Army Corps of Engineers Fisheries Field Unit, Bonneville Lock and Dam, for the U.S. Army Corp of Engineers, Portland District, Portland, Oregon.

Sweeney, C., G. Johnson, and A. Giorgi. 2006. *Surface Bypass Program Comprehensive Review Report.* 30% draft submitted to the U.S. Army Engineer District, Portland, Oregon.

Thorne, R. E. and E. S. Kuehl. 1989. *Evaluation of Hydroacoustics Techniques for Assessment of Juvenile Fish Passage at Bonneville Powerhouse I*. Final Report Prepared for U.S. Army Corps of Engineers, Portland District, by BioSonics, Inc., Seattle, Washington.

Thorne, R.E. and G.E. Johnson. 1993. "A review of hydroacoustic studies for estimation of salmonid downriver migration past hydroelectric facilities on the Columbia and Snake Rivers in the 1980s." *Reviews in Fisheries Science*. 1 (1) 27-56.

Uremovich, B. L., S. P. Cramer, C. F. Willis, and C. O. Junge. 1980. *Passage of Juvenile Salmonids through the Ice-Trash Sluiceway and Squawfish Predation at Bonneville Dam, 1980*. Prepared for the U.S. Army Corps of Engineers - Portland District by the Oregon Department of Fish and Wildlife.

USACE (U.S. Army Corps of Engineers). 2001. *Design Documentation Report – Bonneville Second Powerhouse High Flow Outfall Bypass System*. U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

USACE. 1995. *Lower Snake and Columbia Rivers Surface Bypass and Collection Systems Prototype Development Program*. Portland and Walla Walla Districts, U.S. Corps of Engineers. August 1995.

WDFW, ODFW, IDFG, and CRITFC. 1995. *Spill and 1995 risk management.* Joint Report by the Washington Department of Fish and Wildlife, Oregon Department of Fish and Wildlife, Idaho Fish and Game, and the Columbia River Inter-Tribal Fish Commission.

Willis, C. F. and B. L. Uremovich. 1981. *Evaluation of the Ice and Trash Sluiceway at Bonneville Dam as a Bypass System for Juvenile Salmonids, 1981*. Prepared for the U.S. Army Corps of Engineers - Portland District, by the Oregon Department of Fish and Wildlife.